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HIGH DEFECTS OF THE ATRIAL SEPTUM

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INTRODUCTION

WITH the extension of surgery to defects within the heart these defects have quickly become the subject of intense study. New information concerning many of them has appeared and there has been a wider dissemination of old knowledge. Attention has been paid to the abnormal anatomy and to the abnormal function and new diagnostic techniques have been developed. Special problems and unusual complications which may be associated with the surgical treatment of these defects have been described. In this presentation, I will deal with some of these features of one particular defect—a subtype of the atrial septal defects. The complications of surgical repair will be emphasized.

PATHOLOGIC ANATOMY

Foramen Ovale Defect.—The most frequent anatomic type of atrial septal defect is the foramen ovale defect (Fig. 1, *A*). Among 66 patients with atrial septal defects, 78 per cent were of this type. Fortunately, this is the easiest type to repair. There are no dangerous structures near it and there is enough septal wall around it so that the edges may simply be sewn together. It has been repaired successfully by either closed or open operative techniques, although I favor an open technique, employing hypothermia.

Low Defect.—The defect illustrated in Fig. 1, *B*, and designated as a low, a persistent ostium primum, or an incomplete type of common atrioventricular canal defect presents a much more serious problem. One edge of the defect is

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formed by the crest of the ventricular septum and the fusion of the right and left atrioventricular valves. This defect is near the atrioventricular node and, due to injury of this node, complete heart block may follow repair. In addition, the valve deformity, which actually is part of this defect, is difficult to correct.

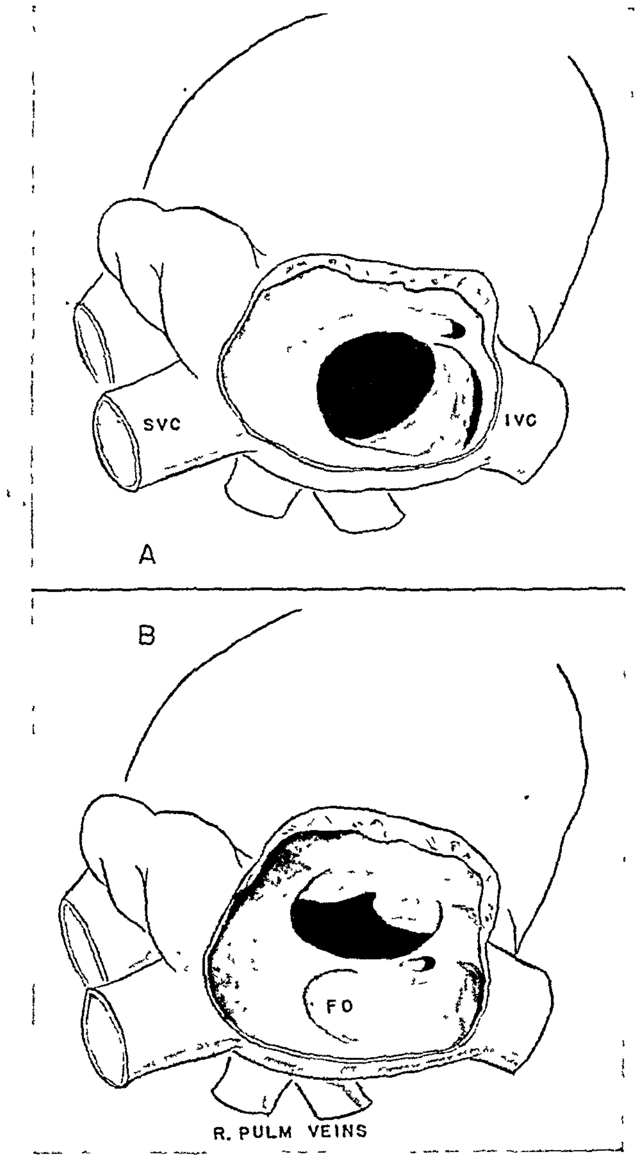


Fig. 1.—*A*, Shows a foramen ovale defect viewed from the right side, as at an operation, but with the atrial wall removed. The patient's head is to the viewer's left. The defect does not have a distinct lower margin but otherwise it offers no special problems in repair.

B, A persistent ostium primum defect with the foramen ovale normally closed. The notched aortic cusp of the mitral valve is seen through the defect. The ventricular septum is located superiorly and to the right in this picture but it is actually "lower" than or inferior to the defect when the patient is erect.

Furthermore, stitches in the ventricular septum may pull out. There are a number of difficult problems associated with attempts to repair this defect but I will not discuss them further at this time. I am concerned here with a simpler defect, the high defect which, nonetheless, offers serious hazards to repair.

High Defect.—The high defect, illustrated in Fig. 2, should be distinguished from the foramen ovale defect. It is located just inferior to the superior vena cava. The superior edge of the atrial septum in this area is a sharp crescent which forms the inferior margin of the defect but superiorly the defect has no definite margin, since there is no remnant of the septum above it. Appropriately, at least from the anatomic point of view, this defect has been called an abnormal entry of the superior vena cava into both the right and left atria.

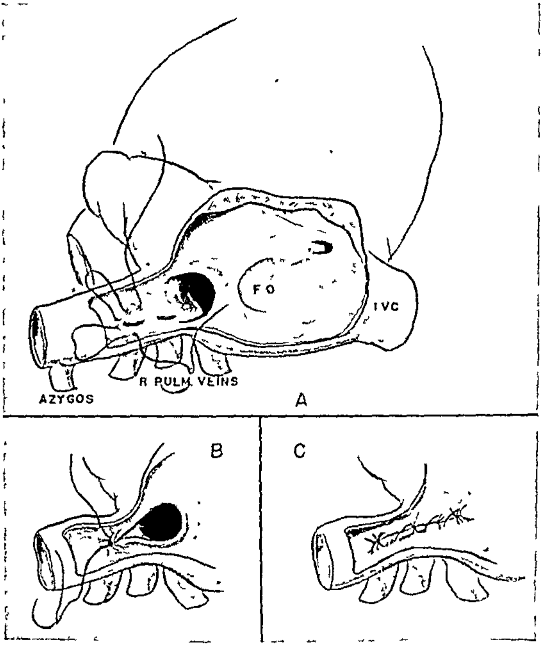


Fig. 2.—High defect of the atrial septum

A, This shows the relationship of the defect to the septum, the fossa ovalis, the superior vena cava, and the right pulmonary veins The orientation is from the surgeon's point of view as he stands on the right side of the operating table The first repair stitch has been placed

B, The first repair stitch has been tied

C, Closure of the defect is completed and some narrowing of the vena cava is evident.

More than the vena cava and the atrial septum are involved, however, for the defect is invariably associated with a partial anomalous, pulmonary venous drainage. The veins draining the right upper and middle lobe, usually with separate openings, enter the lower part of the superior vena cava just above the defect itself. The azygos vein terminates higher than usual, entering the vena cava superiorly to these anomalous veins This defect is superior to and separate from the site of the foramen ovale though there may be the foramen ovale type, as there was in 4 of our 12 patients. To carry this association between the foramen ovale defect and the high defect farther there is, I think, a type of defect in which the band of septum between the high defect and the foramen ovale defect has absorbed resulting in a large "combined" defect. I have encountered this type only once.

The high type of atrial septal defect was described as early as 1867[18] but only occasional reports of individual cases appeared prior to our description in 1955.[9] More recently the attention of a number of surgeons has been directed to it. At the present time the pathologic anatomy of the defect is quite well understood and H. J. C. Swan of the Mayo Clinic has recently described the pathologic physiology in an excellent report on a group of carefully studied cases.[16] A search for the functional alterations he described will lead to a preoperative diagnosis in most cases. After the diagnosis has been made, surgery is indicated in most patients with this anomaly. The repair has probably been thought of as relatively straightforward with either a closed or open technique. Unfortunately, the repair is difficult and there are some special hazards to which attention has not yet been called.

CASE MATERIAL

The high defect has been the second most common atrial septal defect in our experience. Among 66 patients, all operated upon, the high defect was found 12 times. In the first 2, we did not understand the nature of the defect and only made the diagnosis in retrospect. In the third patient, however, there was a foramen ovale defect in addition to the high defect so we were forced to see that the high defect was a separate lesion. I have had no trouble recognizing it since then. Among the 12 patients, there were 7 females and 5 males, while among the remainder of the patients with atrial septal defects there were 40 females and 14 males. There may be a more nearly equal sex distribution in those with high defects than there is among those with other atrial septal defects. Age ranged from 5 to 52 years for the high defects, about the same as for the entire group.

Among the 12 patients with high defects, there were 2 operative deaths. The first death was in a 55-year-old man who died of irreversible ventricular fibrillation on the operating table—death attributable to hypothermia, the technique used for doing these open heart operations. The second death was in a 26-year-old man who died of thrombosis of the superior vena cava—a complication peculiar to the repair of this particular type of defect.

COMPLICATIONS OF REPAIR

To repair this defect we have used a row of sutures placed so that the aberrant pulmonary veins are directed into the left atrium as the defect is closed. This technique is illustrated in Fig. 2. The defect is repaired through an incision in the upper part of the atrium and lower part of the superior vena cava The objective of correcting both the anomalous venous connection and the septal defect is sound, of course, but the technique for obtaining this objective is not satisfactory We have had a number of complications

The upper half purse-string stitch may not completely close the very upper end of the repair for, in 2 cases, the catheter slipped out into the lung during postoperative catheterization as it had preoperatively This difficulty may not be of great importance, however, for there was no evidence of a shunt in these cases postoperatively (a shunt was diagnosed when there was more than 2 volumes per cent increase in oxygen saturation between the venae cavae and the atrium) Apparently the catheter will slide out through a small crevice

More serious have been the instances of venous thrombosis at the site of repair Such complications have occurred in 4 of the 12 cases All except one of these appeared as lobar pulmonary congestion in the early postoperative period indicating that the vein from the right upper lobe was occluded Fig 3 shows the appearance of this complication on roentgenography In the patient illustrated, there was hemoptysis and a febrile course Two other patients apparently were little troubled by the complication It is not usually fatal[5, 16] Nonetheless, when the lung recovers, the venous blood from the involved lobe must drain into the systemic venous system thus producing a left-to right shunt, the situation that the operation was expected to correct

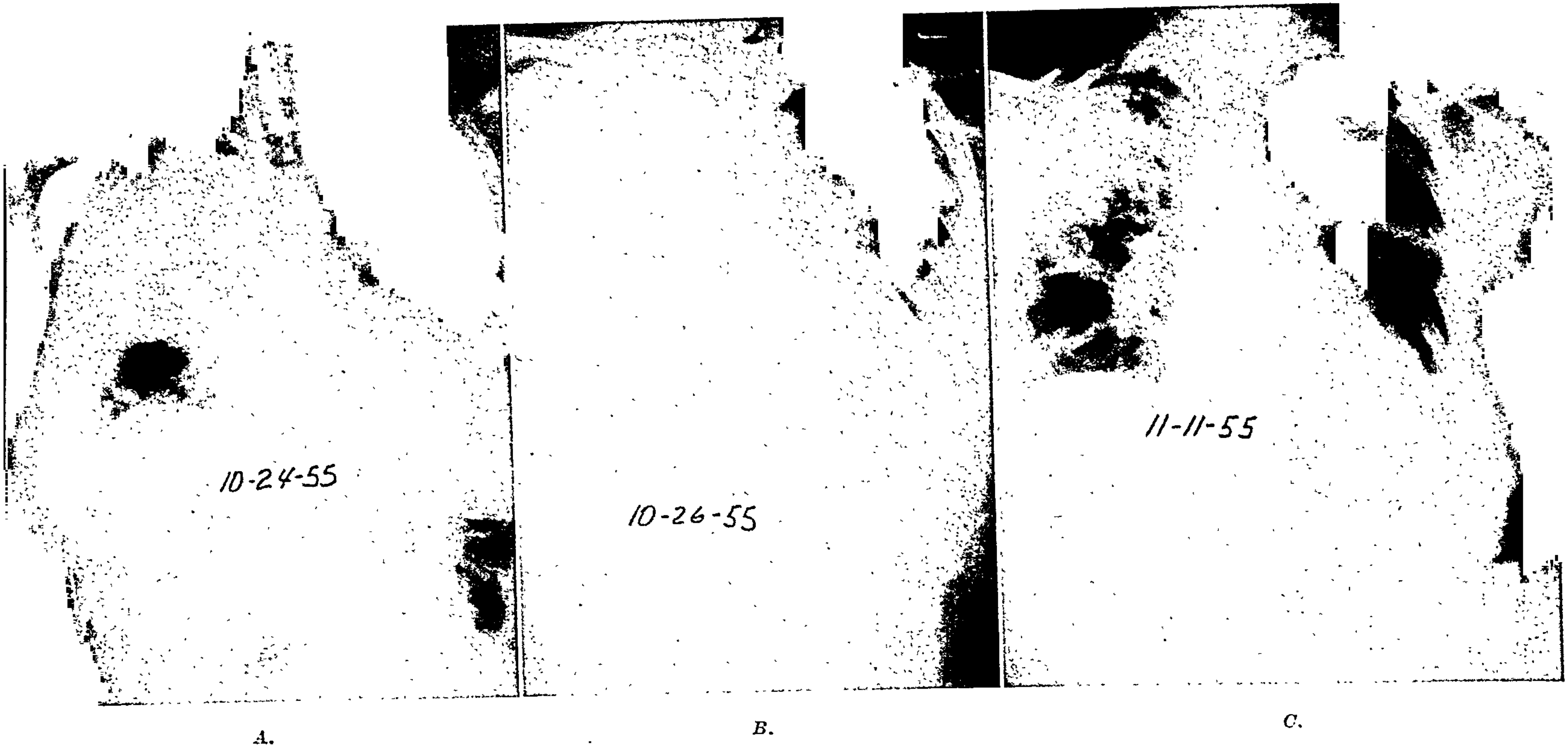
Thrombosis originating at the site of the repair may occlude the superior vena cava as well as the pulmonary veins This happened in one of our patients and it caused his death Apparently in trying to avoid making the channel for the pulmonary veins too narrow the vena cava was narrowed too much and it thrombosed postoperatively Unfortunately, the azygos vein had been ligated and thus closed an important potential drainage channel of the superior vena cava This complication happened in the eleventh patient with a high defect Probably because it had not occurred earlier, I did not consider it as a serious possibility despite the fact that narrowing of the vena cava, caused by the repair, obviously set the stage for it When occlusion of the vena cava did occur I did not recognize it In contrast to the chronic course usually described in the literature for patients with obstruction of the superior vena cava[11, 1, 17] this patient passed rapidly to a fatal termination

CASE REPORT

The patient was a 26 year old man (Passavant Memorial Hospital No 57 2161) known to have congenital heart disease since childhood, who underwent right heart catheterization in January, 1957, at which time a diagnosis of high atrial septal defect was made

The defect was repaired on April 10, 1957 under direct vision with the aid of hypothermia After completion of the repair the superior vena cava was narrow and there was cyanosis of the face while the patient was still on the operating table but blood was flowing through the vena cava

Postoperatively, the patient did well the first day but about 36 hours after surgery he became lethargic This lethargy gradually deepened into coma during the next 3 or 4 hours The temperature went up to 104 6° F and respiration failed A tracheotomy was done and an artificial respirator was employed The temperature was lowered with surface cooling[10] The blood pressure fell and it was partially maintained with transfus



A. B. C.

Fig. 3.—Roentgenograms showing three stages in the progression and resolution of right upper lobe congestion resulting from thrombosis of the right superior pulmonary vein.

A, Beginning congestion 3 days postoperatively.

B, Massive consolidation of right upper lobe 5 days postoperatively. The patient had hemoptysis at this time.

C, Clearing of lung 3 weeks postoperatively. The patient was asymptomatic at this time.

Levophed. Congestion of the right upper lobe, indicating thrombosis of the right superior pulmonary vein, appeared on the second postoperative day (after respiratory failure and coma had developed). Spontaneous breathing did not return and he never regained consciousness. He died on the fourth postoperative day.

At autopsy examination there was a thrombosis originating at the surgical repair which obstructed the superior vena cava and the pulmonary veins from the right upper and middle lobes. There was a generalized hemorrhage into the alveolar spaces of the right upper lobe and the alveolar membranes were edematous.

The brain was soft and edematous and the subarachnoid vessels were dilated. There was a diffuse hemorrhagic necrosis of the right cerebellar lobe involving both white and gray matter. Sections through the right temporal lobe and adjacent thalamus showed necrosis of glial cells and absence of neurons.

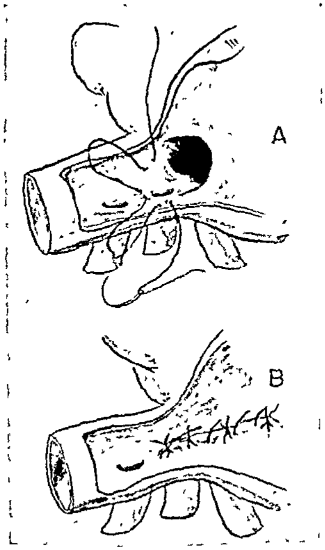


Fig. 4.—An alternative method of repairing the high atrial septal defect.
A, The first repair stitch is placed below the highest anomalous pulmonary vein.
B, Repair completed. The highest pulmonary vein is still connected anomalously to the superior vena cava but the vessels are not constricted.

IMPROVING THE TECHNIQUE OF REPAIR

Other surgeons encountering this defect have apparently used slightly different methods to repair it but it is my impression that these methods all involve narrowing of the blood channels and the introduction of foreign material in the form of sutures, plastic sponge, or both. There is probably a serious risk of thrombosis.

Perhaps the simplest way to avoid this danger and yet achieve a satisfactory repair, at the present time, is illustrated in Fig. 4. The atrial septal defect is closed but the highest abnormal vein is simply not disturbed. .. first patient with a high defect actually had this operation because we did not know enough about the defect then to do a more complex operation. We overlooked the anomalous vein. The patient has an excellent clinical result and his heart has decreased in size. As an alternative the vein could be tied off but then, after a period of severe congestion, the venous drainage would be re-established to the vena cava anyway by way of the azygos system. The shunt through one lobe is not great and it can be safely ignored. If it seemed necessary to eliminate this shunt, the lobe could be resected.

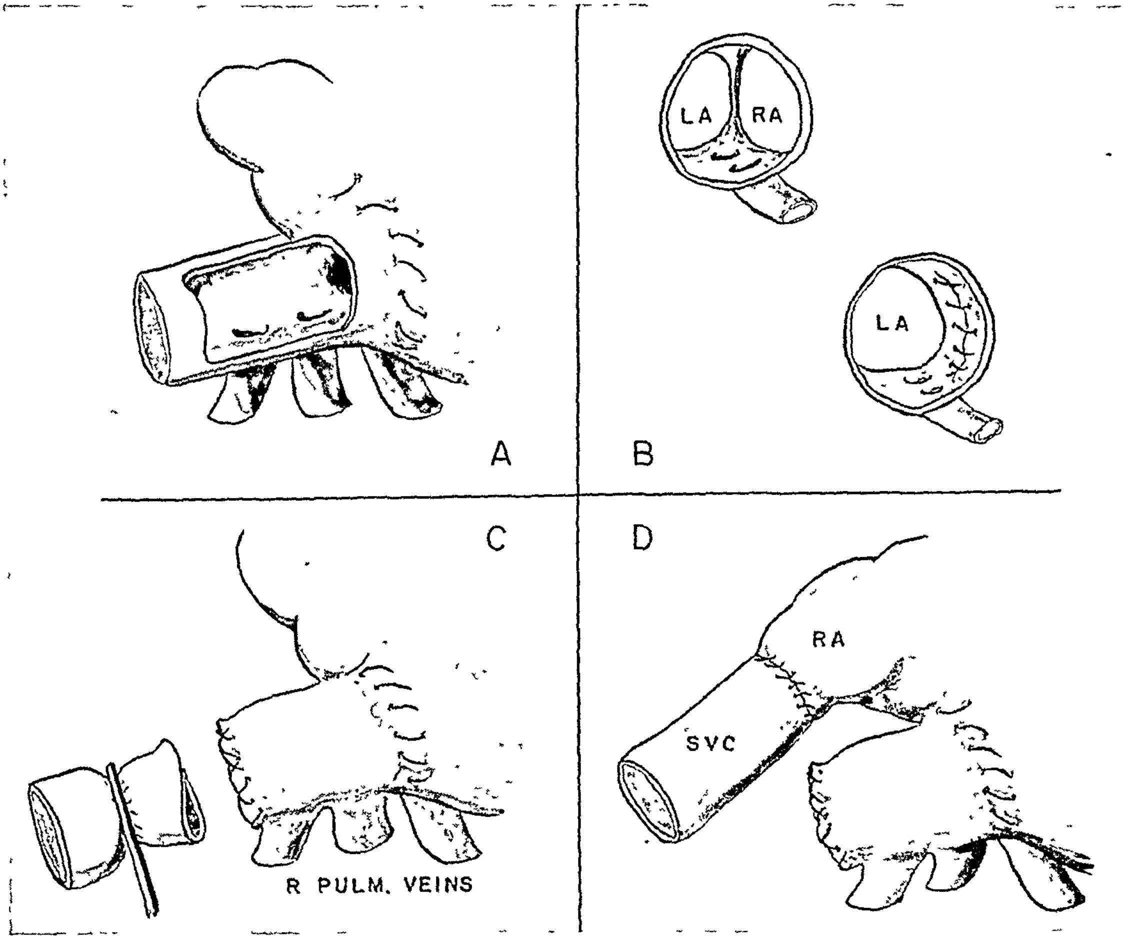


Fig. 5.—A second alternative for repairing the high defect.

A, The right atrial wall is stitched to the lower margin of the defect thus diverting the anomalous pulmonary veins and the superior vena cava into the left atrium.

B, *The same step shown in A but viewed from above looking into the lumen of the* superior vena cava

C, The superior vena cava is divided and the distal end closed.

D, The superior vena cava anastomosed to the right atrial appendage.

Another possible way of managing the situation with achievement of complete repair is illustrated in Fig. 5. The opening of the vena cava into the auricles is revised so that the cava drains entirely into the left atrium instead of into both the right and left atria. Thus, the aberrant pulmonary veins are directed properly into the left atrium with no narrowing of their course, but the vena cava is draining into the wrong atrium. The vena cava must then be divided above the pulmonary veins and anastomosed to the right atrium. I have not yet used this technique in patients because I considered such a venous anastomosis dangerous in itself, but we have been stimulated to study the problem of venous anastomoses in the laboratory.

ANASTOMOSIS OF THE SUPERIOR VENA CAVA TO THE RIGHT ATRIUM

Some time ago we employed Ivalon sponge blood vessels to substitute for the vena cava[1] and learned, as many others have, that grafts, or, for that matter, even anastomoses of the large veins are very likely to become occluded. Sometimes the vessels stay open for months but the contraction of scar tissue unopposed by a significant intraluminal pressure tends to narrow the lumen and occlusion may finally occur.

The venous anastomosis which we are interested in here, between the superior vena cava and the right atrium, has been studied experimentally by Gerbode[3] who achieved good results in dogs when a careful anastomosis was made between the vena cava, just above the azygos vein, and right atrial appendage. In 7 of 10 dogs, the anastomosis remained open and some of these animals were followed for as long as 5 years.[4] In these anastomoses there was probably not much tension but as part of a treatment for the high defect tension would be unavoidable unless a graft were used. Anastomoses of various types or grafts have been employed to relieve superior vena cava obstruction in a few human cases.[6, 7, 8, 13, 14] Some of the results have been good, at least for awhile, but most of these patients were not followed long since the venous obstruction was usually due to cancer. In man, an anastomosis between the vena cava and the atrium might remain open more often than it does in dogs simply because the cava is larger but before using this anastomosis in man we hoped to learn a technique that would work regularly in dogs.

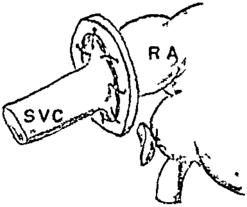


Fig. 6.—Experimental method of anastomosing the superior vena cava to the right atrial appendage. The anastomosis is attached circumferentially to a ring of Teflon.

Because of our earlier experience with Ivalon grafts we have not used grafts. Instead we have concentrated on the problem of an anastomosis, done under some tension, between the vena cava, above the termination of the azygos vein, and the right atrium.[2] In these circumstances a simple everting anastomosis failed. We then used a Teflon tube insert which was placed inside the anastomosis to hold it open. Though the actual site of anastomosis between the vena cava and the atrium could not contract down, scar tissue at either end of the tube, external to the vessel wall, narrowed the lumen and thrombosis finally occluded it. Up to the present we have had our best results with a ring of Teflon placed externally to the anastomosis which is used to hold the anastomosis open (Fig. 6). The everting anastomosis is stitched out to this ring after it has been completed. The ring is left in place so that it may hold the anastomosis open during the healing. We have used it in 12 dogs and the anastomosis has been studied with angiograms in 7. It remains open in 6 of these 7 but they have not yet been followed long enough to satisfy us.

DISCUSSION

When an anomaly, previously inoperable, becomes the proper object of surgical therapy there is a strong new stimulus to investigate all aspects of the condition. The high atrial septal defect, although a relatively uncommon disease, has become the subject of this new scrutiny. Its surgical anatomy is well understood at the present time and there is some comprehension of its embryological development. The abnormal physiology has been quite well described and, through this physiologic knowledge, new tests have been developed that permit its differential diagnosis from other atrial septal defects.

Although much of this new understanding of the defect is a result of the fact that it is now surgically correctable, the surgical repair is still not ideal. There is a propensity to the occurrence of serious complications which are clearly the result of the repair technique. Thrombosis of the anomalous pulmonary veins has been difficult to avoid, and even thrombosis of the superior vena cava may occur. The repair technique must be altered; but if it is altered in one apparently satisfactory way, it will be necessary to do a venous anastomosis (between the superior vena cava and the right atrium) which may be hazardous in itself. Perhaps the safest repair at the present time is a compromise which leaves the right superior pulmonary vein still anomalously connected to the superior vena cava.

SUMMARY

1. The high atrial septal defect can be distinguished from the foramen ovale defect and from the persistent ostium primum defect because of its unique anatomic features.

2. The complications of pulmonary venous thrombosis and thrombosis of the superior vena cava that have arisen in the repair of 12 high atrial septal defects are described.

3. In order to avoid these complications one can forego complete correction of the defect by leaving the abnormal connection of the right superior pulmonary vein to the superior vena cava. Another alternative to be explored involves anastomosis of the superior vena cava to the right atrium.

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THE ELECTROCARDIOGRAM IN OPEN HEART SURGERY

Disturbances in the Right Ventricular Conduction

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THE ADVENT of open heart surgery has raised many important questions that require elucidation. Some of these are concerned with the electrocardiographic changes during and after surgical procedures. It is the purpose of this paper to present a study of the disturbances in the right ventricular conduction which appeared after operation in patients who had undergone open heart surgery. Other disturbances in the conduction system such as auriculoventricular blocks have also been briefly considered in this work.

MATERIAL AND METHODS

Sixty-three of the first 100 patients who have been subjected to open heart surgery at St. Vincent Charity Hospital were studied by electrocardiograms taken before, during, and after the surgical procedure (Table I).

TABLE I. DISTRIBUTION OF CONGENITAL HEART DEFECTS IN 63 PATIENTS OPERATED UNDER DIRECT VISION

Interatrial septal defects	15
Pure valvular pulmonic stenosis	10
Valvular pulmonic stenosis plus interatrial septal defect	2
Valvular pulmonic stenosis plus patent ductus arteriosus	1
Interventricular septal defects	18
Pure infundibular pulmonic stenosis	2
Tetralogy of Fallot	8
Tetralogy of Fallot plus atrial septal defect	3
Infundibular pulmonic stenosis plus interventricular septal defect	4

All patients had a complete preoperative electrocardiogram (6 limb leads and precordial leads from V_1 to V_6). Recording of at least one lead during operation was undertaken in all cases. The great majority had a complete 12-lead postoperative electrocardiogram and many of them had multiple tracings in the follow-up. In a few patients who died postoperatively, it was possible to record only the limb leads due to dressings on the precordium. In order to establish a criterion for the changes indicating disturbances in the right ventricular conduction following surgery, we have divided the postoperative tracings into three groups.

From the St. Vincent Charity Hospital, Cleveland, Ohio.

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Group 1.—No changes. No alterations suggestive of disturbances in the right ventricular conduction were present.

Group 2.—First degree changes—appearance of R′ or R′S′ in Lead V_1 but without any significant increase in the duration of the QRS complex (less than 0.015 seconds).

Group 3.—Second degree changes—appearance of R′ or R′S′ pattern in Lead V_1, wide S waves in Lead I and wide R waves in aVR. The duration of the QRS complex is significantly increased when compared with that before surgery (equal or more than 0.02 seconds).

From now on the designations, "no changes," "first degree changes," and "second degree changes" will be used to indicate the alterations in the right ventricular conduction.

ANALYSIS

1. *Interatrial Septal Defects.*—All 15 patients of this group presented different types of premature beats: atrial, nodal and ventricular, during the surgical procedure particularly during the cardiotomy. In a few cases these premature beats remained for several hours after operation, but in no case did they persist for more than 2 days (Table II).

In 14 out of the 15 cases in this series, there existed an R′ wave in Lead V_1 before the operation. This morphology is known to be a frequent finding in the electrocardiograms of patients with interatrial septal defects.[2] Following surgery in 13 of these cases, the R′ disappeared or decreased in voltage. In one case only the amplitude of this wave remained the same (Case 4). One patient in this series of interatrial septal defect had an RS pattern in *the first* classical precordial lead before surgery. In this case no changes were observed after the correction of the defect. Applying the criteria we have described above, we may say that of the patients with interatrial septal defects none exhibited disturbances in the right ventricular conduction after surgical correction.

2. *Valvular Pulmonic Stenosis.*—Thirteen patients presenting this malformation have undergone open heart surgery. In 10 of the cases the valvular defect was not associated with any other anomaly. The remaining 3 had other congenital defects, 2 interatrial septal defects and 1 patent ductus arteriosus. Applying our criteria we will have the following distribution for the electrocardiograms of the patients in this series: Group 1—5 cases or 38 per cent, Group 2—8 cases or 62 per cent, Group 3—no cases or 0 per cent (Fig. 1).

As one can see the marked changes in the right ventricular conduction which characterize the group, 3 were absent in patients who had undergone pulmonic valvulotomy. However, in 1 case, immediately after the commissurotomy, electrocardiographic changes as described in Group 3 appeared, these were transitory and disappeared in 36 hours (Fig. 2).

In only 2 cases was the transarterial technique used, in the remaining 11 a cardiotomy through the outflow tract of the right ventricle was per[illegible]. As

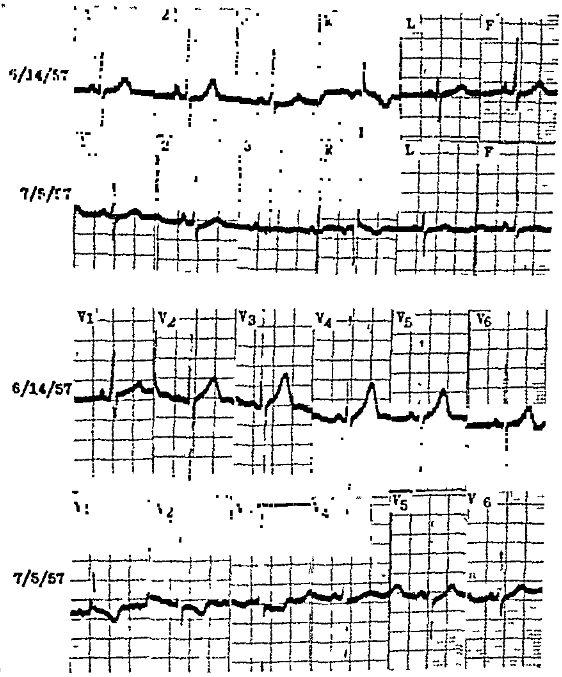

Fig. 1.—Valvular Pulmonic Stenosis. Appearance of first-degree changes after surgery.

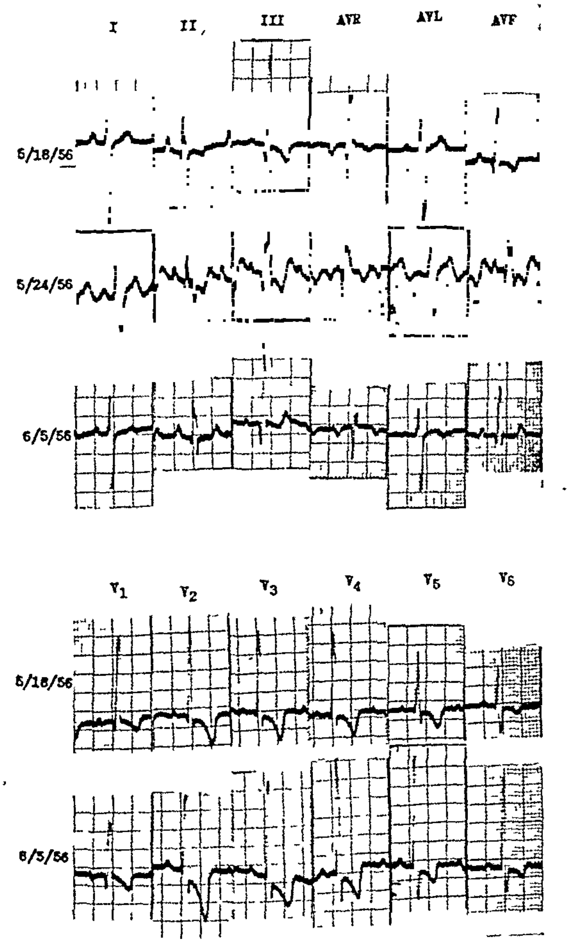

Fig. 2.—Transitory disturbances are shown in the right ventricular conduction as we can see in the record taken May 24, 1956 (a few hours after surgery). These changes disappeared and were not seen any more in the last record (June 5, 1956).

TABLE II. ECG CHANGES FOLLOWING SURGERY IN 15 PATIENTS WITH INTERATRIAL SEPTAL DEFECT

CASES	BEFORE		AFTER	
1.	R = 2.2 R′ = 8.5	S = 0.5 S′ = 2.5	R = 1.5 R′ = 8	S = 3.5 No S′
2.	R = 1.5 R′ = 5.2	S = 0.1 S = 0.5	R = 1 R′ = 3	S = 1.5 No S′
3.	R = 18	S = 4	R = 14	No S
4.	R = 2.2 R′ = 4	S = 0.1 S′ = 8.5	R = 1 R′ = 4	S = 1 S′ = 0.5
5.	R = 0.3 R′ = 10.5	S = 2.5	R = 0.1 S = 3	R′ = 8
6.	R = 0.1 R′ = 2	S = 0.2 S′ = 2	R = 0.5 No R′	S = 2 No S′
7.	R = 0.5 R′ = 5.5	S = 4	R = 0.5 R′ = 4.5	S = 3
8.	R = 1.5 R′ = 14	S = 1 S′ = 1	R = 2 R′ = 5	S = 6 No S′
9.	R = 2.5 R′ = 1	S = 1.2 S′ = 1	R = 3.3 R′ = 0.8	S = 0.3 S′ = 1
10.	R = 1 R′ = 9	S = 1.2 S′ = 5	R = 17 No R′	No S No S′
11.	R = 1 R′ = 5	S = 1.5	R = 2.2 No R′	S = 7
12.	R = 2.5 R′ = 7.5	S = 4	R = 2 R′ = 6	S = 4
13.	R = 3 R′ = 8	S = 2	R = 2 R′ = 4	S = 2
14.	R = 5 R′ = 7	S = 1.5	R = 4 R′ = 3	S = 2
15.	R = 2.5 R′ = 4.5	S = 1	R = 2 R′ = 2	S = 1.5

in the series of interatrial septal defects, our records showed several types of premature beats during operation which disappeared in the first 48 hours after surgery. In the 8 cases in which first-degree changes were present, they were seen at the moment of the valvular commissurotomy and persisted.

3. *Interventricular Septal Defects.*—In 18 patients, closure of interventricular septal defects was performed under direct vision. The comparative study of the electrocardiographic tracings showed that after surgery only 1 case could be included in Group 1, 7 patients presented first-degree changes (Group 2), and 10 exhibited alterations compatible with those described in Group 3 (Figs. 3, 4, 5).

All electrocardiographic changes appeared during the closure of the defect. Besides the already mentioned premature beats which were seen in all patients of this series of interventricular septal defects, in 2 of them, first- and second-degree A-V blocks appeared during the surgical procedure; these, however, were transitory, lasting only 2 or 3 minutes.

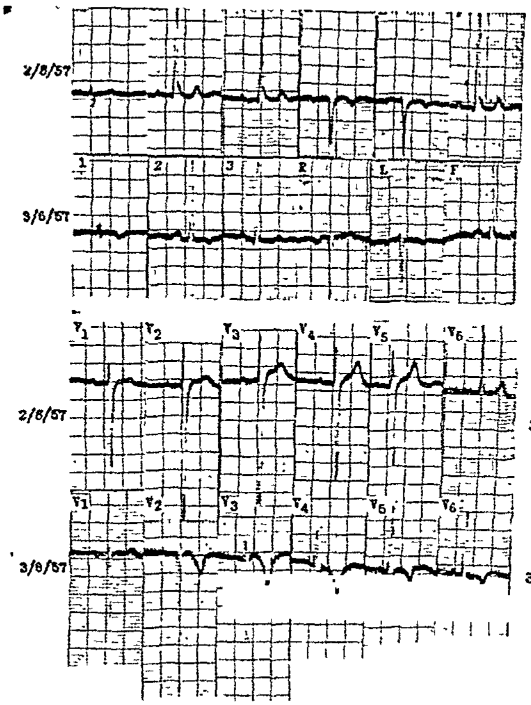

Fig. 3.

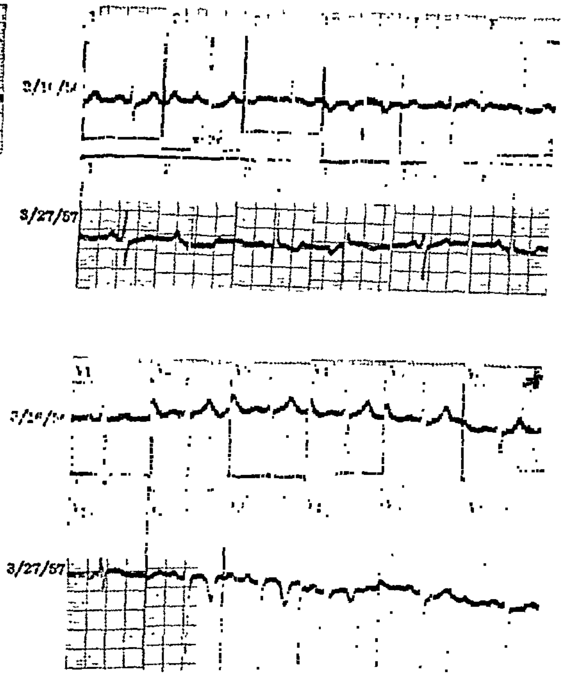

Fig. 4.

Fig. 3.—Pre- and postoperative tracings of a case of interventricular septal defect. No changes in conduction appear following the surgical procedure.

Fig. 4.—First-degree changes seen after surgery in a patient operated upon for interventricular septal defect.

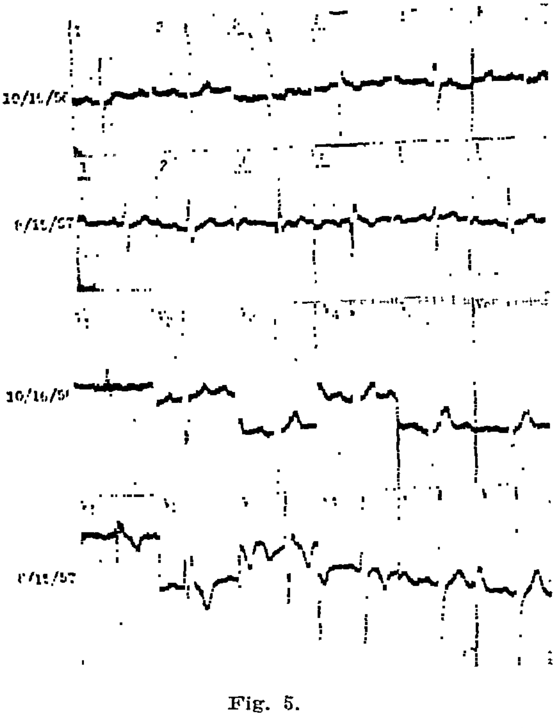

Fig. 5.

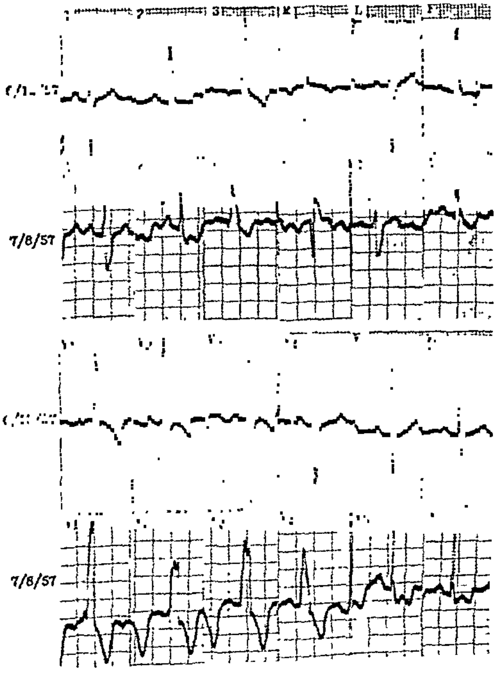

Fig. 6.

Fig. 5.—Appearance of second-degree changes following surgery in a case of interventricular septal defect.

Fig. 6.—Infundibular Pulmonic Stenosis. The postoperative tracing (July 8, 1957) shows the second-degree change pattern.

4. *Infundibular Pulmonic Stenosis.*—In the 2 cases presenting this malformation, the postoperative electrocardiograms were included in Group 3. Transient atrial and ventricular premature beats were also seen in these 2 cases during surgery (Fig. 6).

5. *Tetralogy of Fallot.*—Three out of 11 patients of this series had, also, a communication between the auricles. In 1 it was a real atrial septal defect; in the other 2 the communication was through a patent foramen ovale. One patient died immediately after the closure of the chest wall. In this case, as it is obvious, no postoperative tracing was recorded. In the remaining 10 cases (100 per cent), the electrocardiographic changes appeared either during the resection of the pulmonary infundibulum or during the closure of the septal defect and persisted throughout the postoperative course. These changes were classified as belonging to Group 3. Premature beats were also present in all records during the surgical procedure.

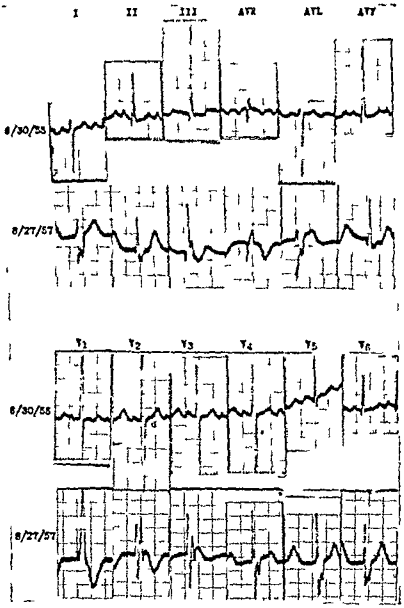

Fig. 7.—Pre- and postoperative records in a case of tetralogy of Fallot. Marked changes (second-degree) in the right ventricular conduction developed after surgery.

In one of them a persistent complete A-V block was noticed following the closure of the interventricular septal defect. This patient, as mentioned above, died in a few minutes (Fig. 7).

6. *Infundibular Pulmonic Stenosis and Interventricular Septal Defect.*—Four patients presented infundibular pulmonic stenosis with associated interventricular septal defect, but without overriding of the aorta. In all, the

characteristic second-degree changes of Group 3 appeared either during the resection of the infundibulum or during the closure of the septal defect and persisted in the postoperative period. As in the other cases, several types of premature beats were present during surgery and persisted for some hours in the postoperative tracing (Fig. 8).

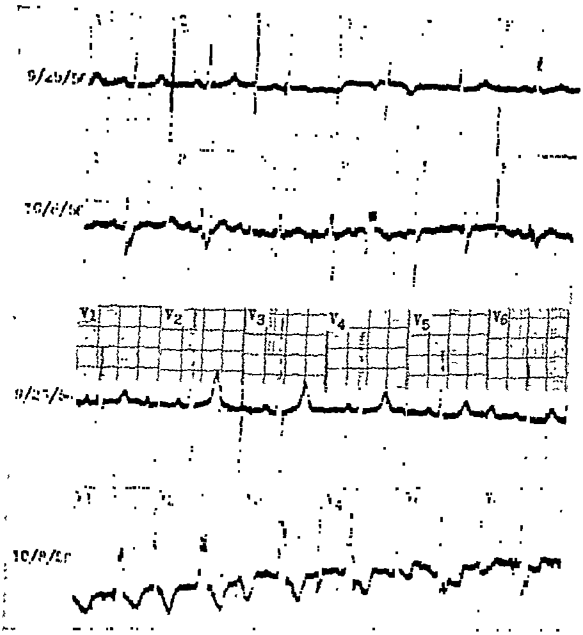

Fig. 8.—Infundibular Pulmonic Stenosis and Interventricular Septal Defect. The postoperative tracing (Oct. 10, 1956) shows the second-degree change pattern.

DISCUSSION

1. *Premature Beats.*—These changes in cardiac rhythm, in spite of its frequency, do not deserve particular consideration. In no case did they cause any disturbance to the patient; they were transitory and disappeared in a short time.

2. *A-V Blocks.*—First- and second-degree blocks were seen in a few cases, but they were transient and innocuous. They possibly occur as a consequence of edema produced by operative maneuvers close to the Aschoff-Towara node.

Complete A-V block was seen in one case of our series. We cannot say whether or not it played an important role in the mechanism of death of this patient. However, we agree with Du Shane[1] that such a disturbance in conduction when produced by mechanical injury, either of the A-V node or of the bundle of His, may cause serious effects upon the circulatory system, particularly during a procedure of such magnitude as open heart surgery.

3. *Disturbances in the Right Ventricular Conduction.*—As is shown in Table III, second-degree changes, very similar to those described in cases of right bundle branch block, appeared in all patients in which a resection of the pulmonary infundibulum was made. It was also seen in a great number of patients in whom closure of the interventricular septal defect had been performed. On the other hand, it was absent in cases of closure of interatrial septal defects or in valvular pulmonic commissurotomy (Table III).

TABLE III. ELECTROCARDIOGRAPHIC CHANGES AFTER OPEN HEART SURGERY

	NUMBER OF CASES	NO CHANGES	1ST DEGREE CHANGES	2ND DEGREE CHANGES
Atrial septal defect	15	15	0	0
Valvular pulmonic stenosis	13	5	8	0
Interventricular septal defect	18	1	7	10
Infundibular pulmonic stenosis	2	0	0	2
Tetralogy of Fallot	11	0	0	11
Infundibular pulmonic stenosis plus interventricular septal defect	4	0	0	4

These observations suggest that there is an area in the right ventricle which is always damaged during infundibular resection; it is also injured in some cases of closure of interventricular septal defects, but does not seem to be involved during valvular pulmonic commissurotomy. We reported an exception in this group. After the opening of the pulmonary valve the patient exhibited marked disturbance in conduction, but these changes disappeared within 36 hours, and probably depended upon a transitory factor involving some zone in the conduction system pathway, notably edema.

The changes in the conductive mechanism which were first seen either during the resection of the infundibulum or during the closure of the interventricular septal defect did not disappear. All patients who have been studied between 6 months and a year after the surgical procedure still had the same disturbances in the right ventricular conduction they presented during and immediately after the operation. Two regions of the conduction pathway could be responsible for the second-degree changes; the right bundle itself or some particular area located in the infundibulum. Studies performed to demonstrate the anatomic localization of the conduction system have shown that the right bundle is situated in a lower position as compared to the pulmonic infundibulum and the majority of the interventricular septal defects.[3, 4] Thus, although we admit that this right bundle branch could be affected in a few cases of infundibular resection or in closure of some defects, it would be unusual to expect its involvement in such a large number of cases. Recent studies[5, 6] indicate that some regions in the outflow tract of the right ventricle, particularly the crista supraventricularis, play an important role in the whole activation of the heart and actually represent almost all sources of the potentials responsible for the last part of the ventricular depolarization. In order to establish the localization of this "forbidden area" of the conduction system involved in our cases, a cardiotomy was performed in 5 dogs using a bypass Sigmamotor pump and a Kay-Cross oxygenator. A catheter with a special electrode was placed in the right auricle and atrial intracavitary electrocardiogram was recorded before the opening of the chest wall. During the cardiotomy, no changes in the right ventricular conduction were seen, but several types of transitory premature beats appeared. Under electrocardiographic control, stitches were placed in the higher parts of the interventricular septum and gradual resection of the infundibulum was performed. No changes in right ventricular conduction were observed until the crista supraventricularis had been cut. At this moment an electrocardiographic pattern very similar to those seen in the "so-[illegible]" right bundle branch block appeared. This was observed in 4 out of [illegible]

(Fig. 9). In the remaining 1, the electrocardiographic changes which developed resembled those found *in* Group 2 of our criteria: i.e., appearance of late R wave, but without increase in duration of the QRS complex (Fig. 10). We feel that in this 1 case the resection of the infundibular region was *not complete*.

One may conclude from our experiments that second-degree changes are the result of operative damage in regions involving the crista *supraventricularis*. This is easily accepted in cases in which the infundibulum is resected. But an explanation must be found for the changes in patients with interventricular septal defect in whom no resection is performed. The closure of high septal defects often necessitates placing stitches in regions close to the crista supraventricularis. This may produce disturbances in the right ventricular conduction similar to those found during correction of the infundibular stenosis. On the other hand there are some cases in which the position of the defect[7] is such so as to produce damage of the right bundle branch itself when the surgical correction is performed (Fig. 11).

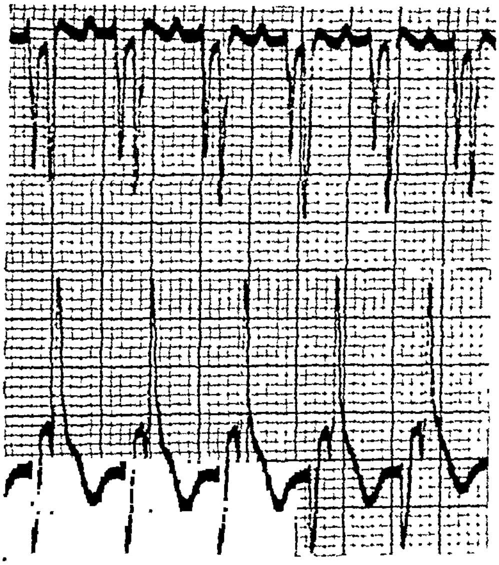

Fig. 9.

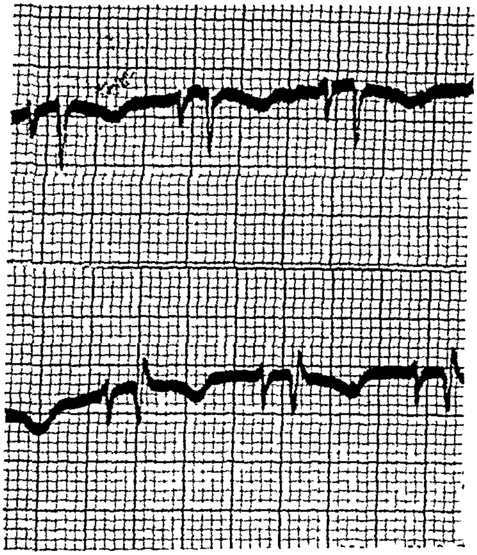

Fig. 10.

Fig. 9.—*Right atrial intracavitary potential* recorded *in* a dog before and after resection of the crista supraventricularis. Following this procedure, marked disturbances in conduction similar to those seen in cases of right bundle branch block appeared.

Fig. 10.—Right atrial intracavitary potential in a dog. After the resection of the pulmonary infundibulum, there appeared changes similar to those found in Group 2 of our criteria. In this case the infundibular resection was not complete.

Thus, it seems probable that right bundle branch block pattern may result not only from involvement of the right bundle itself, but also from damage in the infundibular area, particularly if regions close to the crista supraventricularis are affected. This is not hard to accept if we consider that in many conditions in which dilation and hypertrophy of the basal portions of the right ventricle are present with consequent delay in the conduction of these areas, changes similar to those seen in Group 2 may appear.[8, 9] Thus, resection of the infundibular region or anatomic injury produced by stitches may cause delay in the conduction with development of electrocardiographic changes. We may also add that the degree of alterations in cases of interventricular septal defects depends upon the degree of the injury produced by the operative closure of the septal hole, thus giving us first- and second-degree changes.

Another subject of importance is the effect of these disturbances in right ventricular conduction upon the patients. Although some of us believed at the beginning of this study that these changes in the conductive system could play a role in some patients in the mechanism of death, we now do not regard it as a serious possibility. For instance, in our cases of tetralogy of Fallot all 4 patients who died exhibited these conduction disturbances. However, the 7 who survived also had the same electrocardiographic changes. Further, patients with arteriosclerotic heart disease, Chagas disease,[10] and other cardiopathies frequently present right bundle branch block pattern without any important clinical distress. It is our opinion that the elevated mortality seen after surgery in patients operated on for pure or associated infundibular pulmonic stenosis is concerned with other factors, such as the magnitude of the operative trauma, poor hemodynamic adaptation, and electrolyte disturbance (Table IV).

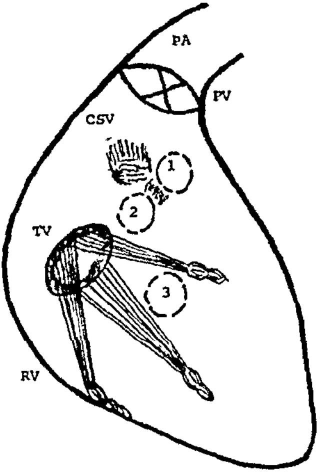

Fig. 11.—*RV*—Right ventricle. *TV*—Tricuspid valve. *CSV*—Crista supraventricularis. *PA*—Pulmonary artery. *PV*—Pulmonary valve.

Defects 1, 2 and 3—Most common locations of intraventricular septal defects. As one can see, Defects No. *1* and No. *2* are situated close to the crista supraventricularis. Defect No. *3* is located near the pathway of the right branch.

SUMMARY

Disturbances in the conductive mechanism of the heart, particularly in the right ventricle, have been frequently seen in the electrocardiograms of patients operated upon for certain types of congenital cardiac malformations.

TABLE IV. CORRELATION BETWEEN MORTALITY AND ELECTROCARDIOGRAPHIC CHANGES

	NUMBER OF SURVIVALS	NO CHANGES	1ST DEGREE CHANGES	2ND DEGREE CHANGES
Atrial septal defect	14	14	0	0
Valvular pulmonic stenosis	13	5	8	0
Interventricular septal defect	12	1	4	7
Infundibular pulmonic stenosis	1	0	0	1
Tetralogy of Fallot	7	0	0	7
Infundibular pulmonic stenosis plus interventricular septal defect	2	0	0	2
	NUMBER OF MORTALITY	NO CHANGES	1ST DEGREE CHANGES	2ND DEGREE CHANGES
Atrial septal defect	1	1	0	0
Valvular pulmonic stenosis	0	-	-	-
Interventricular septal defect	6	0	3	3
Infundibular pulmonic stenosis	1	0	0	1
Tetralogy of Fallot	4	0	0	4
Infundibular pulmonic stenosis plus interventricular septal defect	2	0	0	2

A study of 63 patients who had open heart surgery was undertaken in order to evaluate the incidence and meaning of these disturbances.

A correlation carried out with findings obtained from experimental studies in dogs demonstrated that the changes in the conductive system are related either to the right branch bundle itself, or to the crista supraventricularis and surrounding areas.

It was concluded that these disturbances in conduction were not responsible for the elevated mortality in the group of pure and associated infundibular pulmonic stenosis, but that the deaths in this group depended upon other factors such as operative trauma, hemodynamic inadaptation, and electrolyte disturbances.

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STUDIES OF HEMOLYSIS WITH A PLASTIC-SHEET BUBBLE OXYGENATOR

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DELETERIOUS effects on blood in a pump oxygenator result from a variety of physical actions on the blood. The measurement of hemolysis, expressed by the increase in the value for hemoglobin in the plasma, is used as an index of the degree of undesirable effects exerted on the blood. For the index to reflect properly the deleterious characteristics of a pump oxygenator, determinations of hemoglobin in the plasma probably should be done with the blood circulating in the apparatus only, while the arterial line is connected to the venous line directly. A stated quantity of blood should be circulated at a stated rate of flow.

The plastic sheet bubble oxygenator described by Gott and co-workers,[1] was chosen for this study and comparative determinations of the hemoglobin content of the plasma were carried out with and without an animal in perfusion.

METHODS

For each of the experiments 2,000 c.c. of recently drawn, heparinized blood was obtained from 1 or 2 healthy mongrel dogs of 16 to 30 Kg. in weight by cannulation of the left common carotid artery. For the cannulation, the dogs were anesthetized with 8 to 15 c.c. of a 2.5 per cent solution of thiopental sodium. Five minutes before phlebotomy, heparin was injected intravenously in amounts of 3 mg. per kilogram of body weight.

Dogs which underwent perfusion were healthy mongrels of 8 to 12 Kg. The method for whole body perfusion was identical to that described by Penido and co-workers.[2]

Plastic sheet bubble oxygenators* were used in all experiments. One pump of a roller occlusive type† was used as an artery pump, providing a flow of blood of 550 c.c. per minute. The venous return into a venous reservoir was obtained by gravity. Oxygen flow rates of 2,000 c.c. per minute were used in all experiments, except in one, in which compressed room air was used at the same rate of flow. The connections were made by plastic Tygon tubing with an internal diameter of ½ and 5/16 inch and stainless steel connectors. The venous reservoir was made of Lucite.

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†Rotaflex, Cole Parmer Co., Chicago, Ill.

In the first group of experiments, 2,000 c.c. of recently drawn, heparinized donor blood was circulated in the pump-oxygenator system for 1 hour or 2 hours. In one of these experiments compressed room air was used instead of oxygen. Samples of blood (10 c.c.) for the determination of the hemoglobin content of the plasma were taken before the blood was introduced into the oxygenator, and then from the venous line every 15 minutes during the run.

In the second group of experiments, a dog underwent whole-body perfusion for 1 hour with the same rates of flow for blood and oxygen as before. Samples for the determination of hemoglobin in the plasma were taken before and every 10 minutes during the perfusion. In addition to this procedure, 2,000 c.c. of the blood was circulated in the pump-oxygenator system for periods of a ½ to 1 hour before or after the blood was used for whole-body perfusion.

The samples of blood were carefully collected in test tubes containing 2 drops of heparin, and were centrifuged for 20 minutes at a speed of 1,800 r.p.m. The supernatant plasma was pipetted off. Determinations of plasma hemoglobin were carried out according to the method of Shinowara[3] in the Beckman spectrophotometer. This method was found to be advantageous over other methods because it allows accurate determinations of the content of hemoglobin in the plasma to ranges as low as 5 to 10 mg. per 100 c.c.*

RESULTS

Fig. 1 gives the mean values for plasma hemoglobin as found in 8 experiments, when 2,000 c.c. of blood was circulated in the closed pump-oxygenator circuit for 1 hour or 2 hours. The resulting curve shows a constant rise, reaching an average of 100 mg. of hemoglobin per 100 c.c. of plasma within 30 minutes, of 350 mg. within 60 minutes, and then leveling off gradually toward the end of 120 minutes, reaching a value of 500 mg. of hemoglobin per 100 c.c. of plasma.

An essentially similar curve was obtained when compressed room air was used in the oxygenator instead of oxygen at the same rate of flow (Fig. 2).

To define the role of the pump and the oxygenator independently in the production of hemolysis, the oxygenator was removed from the circuit during a portion of the experiments and was replaced by a glass container. Regardless of whether this was done in the first or second half of the experiment, it could be seen that the pump and tubing accounted for an increase of hemoglobin in the plasma of only about 25 mg. per 100 c.c. within 60 minutes, whereas a typical increase up to 275 mg. per 100 c.c. was produced within 60 minutes by the oxygenator (Fig. 3).

When this pump-oxygenator system was used under the same conditions to perfuse a dog for 1 hour, changes in values for plasma hemoglobin proceeded in an entirely different manner. If marked hemolysis was not present before perfusion was begun, the value for hemoglobin in the plasma increased gradually to 20 to 30 mg. per 100 c.c. within 1 hour (Fig. 4).

When perfusion of an animal was begun after a preliminary run "in vitro" had produced a value of 125 mg. of hemoglobin per 100 c.c. of plasma, a rapid decrease to 12.5 mg. of hemoglobin per 100 c.c. was observed in the

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*We are indebted to Dr. E. J. Baldes of the Mayo Foundation and to Dr. T. T. Myre of Memphis, Tenn., for establishing this method for the determination of plasma hemoglobin in this laboratory.

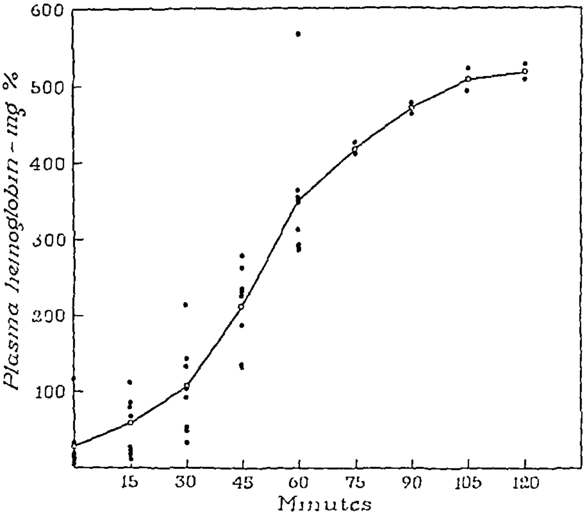

Fig 1 —Mean values for hemoglobin in the plasma when 2,000 c c of blood was culated in the pump-bubble oxygenator system for 2 hours Pump flow 550 c c per minu oxygen flow 2 L per minute

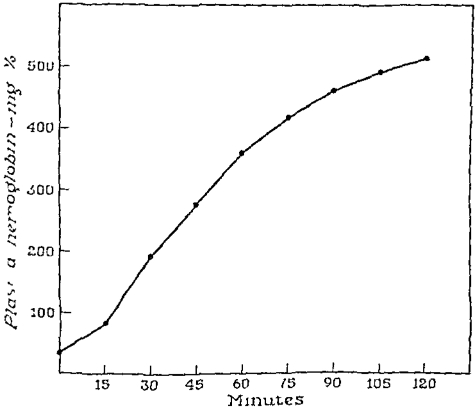

Fig 2 —Concentrations of hemoglobin in the plasma when 2 000 c c of blood was culated in the pump-bubble oxygenator system for 2 hours Pump flow 550 c c per minu compressed room air flow 2 L per minute

next few minutes, and during the actual perfusion the plasma hemoglobin increased only gradually to 40 mg. per 100 c.c. in 1 hour. As 2,000 c.c. of the blood was circulated in the closed pump-oxygenator system after perfusion was terminated, a prompt increase in hemolysis occurred (Fig. 5).

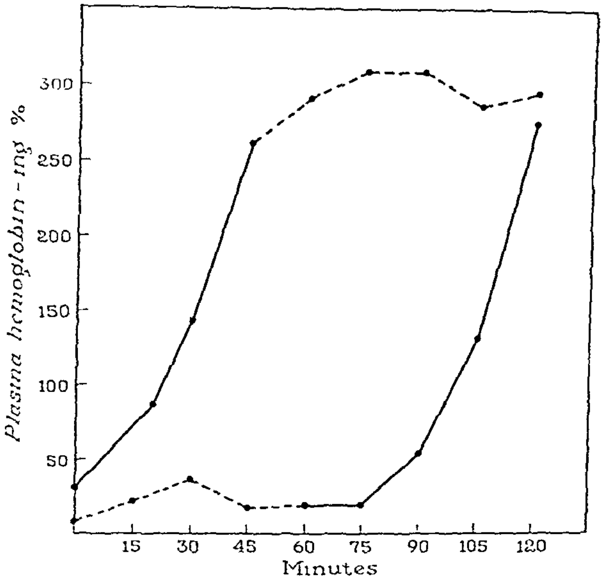

Fig. 3.—Concentrations of hemoglobin in the plasma when 2,000 c.c. of blood was circulated in the pump-bubble oxygenator system (solid lines) or pump and tubing system alone (broken lines), the oxygenator being replaced by a glass container. Pump flow: 550 c.c. per minute; oxygen flow: 2 L. per minute.

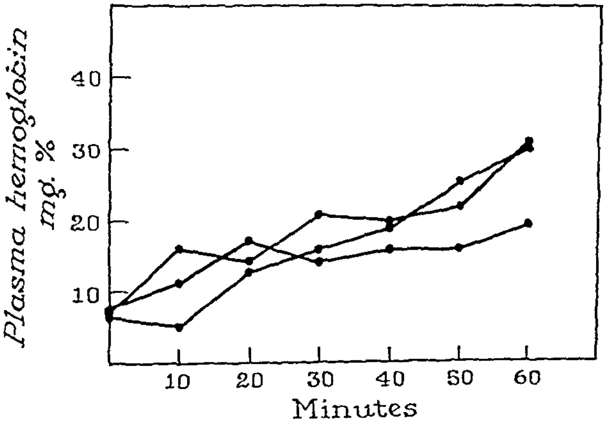

Fig. 4.—Concentrations of hemoglobin in the plasma during whole-body perfusion of dogs (9, 10.7 and 12 Kg.) with 2,000 c.c. of blood from the pump-bubble oxygenator for 1 hour. Pump flow: 550 c.c. per minute; oxygen flow: 2 L. per minute.

To investigate the part played by a living organism in this phenomenon, a comparative experiment "in vitro" was done: a glass container with 800 c.c. of recently drawn, heparinized and unhemolyzed blood was added to the pump-oxygenator circuit after some degree of hemolysis had taken place in 2,000 c.c. of blood during a run of 30 minutes under the usual conditions (Fig. 6).

When fresh blood entered into the circuit a sharp decrease in the concentration of hemoglobin in the plasma was seen, similar to that depicted in Fig. 5. However, in its further course this curve was significantly different.

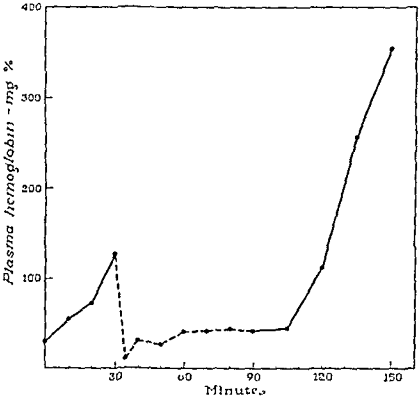

Fig 5.—Concentrations of hemoglobin in the plasma when a dog (9 Kg) was perfused for 1 hour (broken line); 2,000 c c of blood was circulated in the pump-bubble oxygenator 30 minutes prior and 60 minutes after perfusion of the dog (solid line). Pump flow, 550 c c per minute, oxygen flow 2 L per minute

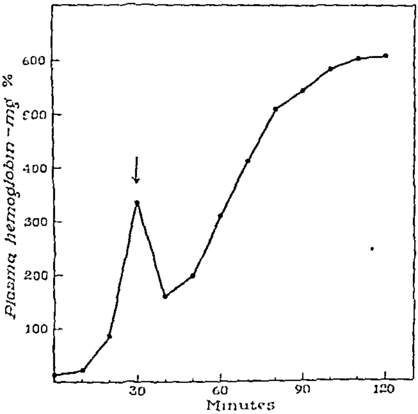

Fig 6—Concentrations of hemoglobin in the plasma when 2,000 c c of blood was circulated in the pump-bubble oxygenator for 2½ hours After 30 minutes a beaker containing 800 c c. of fresh, unhemolyzed blood was introduced into the circuit (arrow) Pump flow: 550 c c per minute, oxygen flow 2 L per minute

In the experiment "in vitro" a steady and rapid increase in hemolysis took place, as would be expected in the use of this pump-oxygenator, in contrast to the low concentrations of hemoglobin in the plasma maintained for 1 hour when a living organism is in the circuit.

COMMENT

In all experiments in which blood was circulated in the pump-oxygenator only, a steady and rapid increase in the concentrations of hemoglobin in the plasma up to 350 mg. per 100 c.c. within 1 hour and 500 mg. per 100 c.c. within 2 hours was observed, whereas during the perfusion of a dog the concentrations of hemoglobin in the plasma did not increase to more than 30 mg. per 100 c.c. In the interpretation of the experiments depicted in Figs. 5 and 6, we are aware of the fact that no quantitative estimations can be made. The initial decrease in both curves is probably due in part to a dilution effect and in part to inadequate mixing of the fresh blood with the hemolyzed blood. The different behavior in the further course of these two curves, however, suggests that the living organism actively removes plasma hemoglobin from the system, or modifies its rate of production in the apparatus. The former is the more probable.

Gott and co-workers[1] found that this oxygenator produces an average increase of 77 mg. of hemoglobin per 100 c.c. of plasma (range from 8 to 185 mg. per 100 c.c.) when dogs are perfused for 1 hour. This is supported by our data. DeWall and co-workers[4] reported values for hemolysis of 33 mg. of hemoglobin per 100 c.c. of plasma (range from 6 to 80 mg. per 100 c.c.) in the clinical use of their oxygenator for the perfusion of man. Recently, Bücherl[5] published results of experiments ''in vitro'' in which he passed oxygen through human donor blood according to the bubble-oxygenator principle. He noted values for hemoglobin in the range of 300 mg. per 100 c.c. of plasma after 1 hour, increasing to the range of 500 mg. per 100 c.c. in the second hour, which is in close agreement with our findings.

It seems that the jets of oxygen entering the blood at the bottom of the oxygenator chamber are the major factors in the production of such intensive hemolysis. In evaluating different arrangements of the oxygen disperser, Gott and co-workers[1] noted extremely high hemolysis (an increase of 971 mg. of hemoglobin per 100 c.c. of plasma) and a 100 per cent mortality rate among 5 dogs when the venous inflow was below the level of the oxygen disperser and oxygen emitted under high pressure through only a few fine holes. Bücherl[5] observed an increase in hemolysis when oxygen flows were higher and, also, when an antifoam substance was added to the blood. This latter fact suggests that the passage of gas through a massive column of blood with the resulting turbulences is the mechanism which causes high hemolysis, and that the foaming does not do so.

It is unlikely that oxygen in itself causes hemolysis, since we found essentially the same values when either pure oxygen or room air was used.

Several factors exert an influence in the proportion of hemoglobin liberated from the plasma by trauma. The percentage volume of red blood cells was found to have a decided influence. The condition of the donor blood, especially if it was drawn from more than one donor, or was stored, certainly may make the blood more or less susceptible to hemolysis. This is obvious not only in increased concentrations of hemoglobin in the plasma of the control sample; there is also the possibility that these erythrocytes are more likely to be affected by trauma. It is known that cohesion of erythrocytes, spheroidicity, changes in the strength of the membrane and heating to 52° to 58° C. definitely increase the mechanical fragility of erythrocytes.[6]

Consideration should be given to the possibility that large amounts of plasma hemoglobin are removed from the blood by the subject during whole-body perfusion if the pump-oxygenator produces high hemolysis. The mechanism of elimination of hemoglobin from the plasma in the blood stream has been studied by many investigators.[7-13] Three possibilities are recognized. After injection of solutions of hemoglobin into the blood stream, the plasma hemoglobin is quickly picked up by the cells of the reticulo-endothelial system, where it is broken down and transformed to bile pigments. This is the only mechanism involved if the concentration of hemoglobin in the plasma stays below a certain level. Above this level, hemoglobin is also excreted through the kidneys. A third way for the elimination of intravascular free hemoglobin was suggested by Fairley.[8] He showed that at higher levels the hemoglobin could be catabolized directly in the blood stream with the formation of methemalbumin.

The renal threshold for hemoglobin in human beings is in the neighborhood of 135 to 250 mg. per 100 c.c. of plasma.[9, 14, 15] For dogs it has been found in the range of 100 to 210 mg. per 100 c.c.[16-20] Once hemoglobinuria has started, it may continue until the concentration has decreased to 30 to 50 mg. per 100 c.c. of plasma.[16] The renal clearance of hemoglobin has been found to lie between 3 and 6 mg. per 100 c.c. of plasma per minute, if the concentration of hemoglobin is 250 mg. per 100 c.c. of plasma.[21] During whole-body perfusion these relationships may be altered, for renal blood flow and renal function are closely related to the rate of perfusion and aortic mean pressure.[22]

Bethard and Plzak[23] injected radioactive labeled solutions of hemoglobin into nephrectomized rats and found that the rates for clearance of the injected material from the plasma in the nephrectomized animals were 30 to 40 per cent of those in normal controls. Flink[10] estimated that after the injection of 1 Gm. of hemoglobin per kilogram of body weight in dogs, 60 to 75 per cent was destroyed by the reticulo-endothelial system.

The reticulo-endothelial system certainly is capable of clearing large amounts of hemoglobin from the plasma, as can be seen in patients who have "acholuric" jaundice, in which the total hemoglobin of the body is disposed of within a few days and up to 10 Gm. of hemoglobin is destroyed in 1 day without the appearance of hemoglobin in the urine. The reticulo-endothelial cells of the spleen, liver, and bone marrow probably are the main foci for the destruction of hemoglobin, but the reticulo-endothelial system of the whole body takes part in the process, so that large amounts of free hemoglobin are cleared from the blood stream within seconds or minutes.

An increase in bilirubin in the plasma should be expected and has been proved to occur within 30 minutes after the injection of solutions of hemoglobin into human beings.[7, 9] The life span of bilirubin molecules in the plasma is thought to be approximately 90 minutes.[11]

The above-mentioned data allow the following interpretation of the fate of plasma hemoglobin in our experiments.

Quantities of up to 350 mg. of free hemoglobin per 100 c.c. of plasma are produced in 1 hour by the pump-oxygenator studied. If there is a subject in perfusion during this time, the failure of free hemoglobin levels in the plasma to rise is most likely caused by the action of the reticulo-endothelial system. Since concentrations of hemoglobin remained below 50 mg. per 100 c.c. of plasma, excretion through the kidneys is unlikely, especially if a reduction in renal blood flow occurs during perfusion.

If it is assumed that the animal removes hemoglobin from the blood at a rate of 300 mg. per 100 c.c. of plasma per hour, the clearance of hemoglobin would be 5.0 mg. of hemoglobin per 100 c.c. of plasma per minute.

The clinical sequelae of hemoglobinemia of moderate degree have been described as consisting of chills, fever, abdominal cramps, and vomiting.[9] Only at high levels would hemoglobinuria result and enhance the dangers of anuria, either by obstruction of the renal tubules by casts and debris of hemoglobin or its derivatives,[24] or on the basis of renal vasoconstriction induced by the presence of extracorpuscular hemoglobin.[25] Hyperbilirubinemia may lead to jaundice if 300 to 500 c.c of blood is completely hemolyzed within a few hours.[13]

It seems that hemoglobinemia and an increased uptake of hemoglobin as encountered in our experiments would cause little damage to the subject, except perhaps for a certain degree of fever. However, the increase in hemoglobin in the plasma is an index of deleterious action on the blood, and other factors may be of greater clinical importance. It can be expected that, with the liberation of hemoglobin from red blood cells, a corresponding amount of red-cell stromata is released. This poorly defined substance has been said to be responsible for more serious sequelae of hemolysis. Barratt and Yorke[23] described the lethal character of red-cell stromata after these workers injected relatively small amounts of the material into rabbits, whereas injection of purified solutions of hemoglobin, even in large amounts, produced no or only slight effects. Peripheral vascular dilatation resulting in hypotension, bradycardia, and impaired cardiac conduction with heart block have been attributed to adenosine triphosphate and related compounds set free within 15 to 30 seconds when red blood cells are destroyed. Deyrup[27] showed that quantities of adenosine derivatives from about 3 to 18 per cent of the erythrocytes hemolyzed in a given sample of blood produce significant hypotensive states, and that postoperative shock has been recognized as a possible complication after hemolysis.[28-32]

Disturbances in the blood-clotting mechanism also have been attributed to hemolysis. Barratt and Yorke[26] thought these disturbances to be due to intravascular separation of fibrin in the blood vessels. Fogelman and co-workers[33] reported marked prolongation of the coagulation time in 5 of 9 animals when high degrees of hemolysis were produced.

SUMMARY

It is suggested that the hemolysis which occurs in the application of a pump oxygenator system should be tested for the pump oxygenator circuit proper without a subject in perfusion

Comparative experiments with a plastic sheet bubble oxygenator have been carried out The pump oxygenator system within 1 hour produced hemolysis resulting in a concentration of 350 mg of hemoglobin per 100 c c of plasma and 500 mg per 100 c c within 2 hours when 2,000 c c of recently drawn, heparinized canine blood was circulated at a pump rate of flow of 550 c c per minute and a flow of oxygen of 2 L per minute With an animal in the circuit the concentration of hemoglobin did not increase more than 30 mg per 100 c c of plasma in 1 hour

The main factor in the production of hemolysis in this apparatus may be the oxygen jets which cause turbulent flows in the bubble chamber

The resulting physiopathologic consequences are discussed It is assumed that during whole body perfusion the reticulo endothelial system continuously removes hemoglobin in the plasma from the blood stream at approximately the same rate as the hemoglobin is produced The rate of clearance was established to be approximately 5 mg per 100 c c of plasma per minute

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EXPERIMENTAL CORONARY ARTERIOGRAPHY

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IN THE TREATMENT of coronary disease, improvement of flow through occluded vessels might in certain circumstances be possible by surgical restoration of patency. This approach is being investigated in many laboratories and has had limited clinical trial. Basic to any promise of success is a method for the accurate delineation of occluded and open vessels. Several methods for experimental[1-10] and clinical[4, 11, 18] coronary arteriography have been designed. These, in the main, utilize radiopaque material introduced into the first part of the aorta by direct puncture[11, 13, 15, 16] or via a tube in a peripheral artery. Temporary occlusion of the aorta by an inflated balloon increases the penetration of the contrast material into the coronary system.[15]

The technique to be described below was not designed primarily for clinical use, but rather to attain the best possible delineation of fine coronary branches for studies of the evolution of collateral circulation. Uniform distribution of contrast medium in high concentration within the coronary arteries has been obtained by a method of retrograde injection, developed in earlier work on other vascular beds,[19] which provides nearly complete displacement of blood by contrast medium during the instant of taking the radiogram. The need to expose the heart for the injection of contrast material is not considered a disadvantage since the method is intended for use in connection with surgical procedures upon the coronary vessels.

MATERIAL AND METHODS

Animals.—The experiments were performed upon 31 adult male and nonpregnant female mongrel dogs, weighing between 18 and 31 Kg.

Technique.—The animals were anesthetized with Nembutal given intravenously. Lung inflation was maintained by intratracheal tube. The left chest was opened through the fifth interspace and the heart was exposed through a longitudinal incision in the pericardium, anterior to the phrenic nerve.

A small primary or secondary branch of the anterior descending coronary artery leading over the surface of the left ventricle, not far below the atrioventricular sulcus, was isolated and incised for cannulation (Fig. 1). Distal

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ligation was required because of free arterial back-bleeding. Note was taken of the development of any myocardial cyanosis. The open end of a heparin-filled polyethylene tube was introduced and passed proximally to the origin of the cannulated branch and secured with a fine silk tie and one or two fine stitches. The tubes used for cannulation ranged in size from PE 60 to PE 190 (Intramedic scale—outer diameters 1.22 to 1.70 mm.).

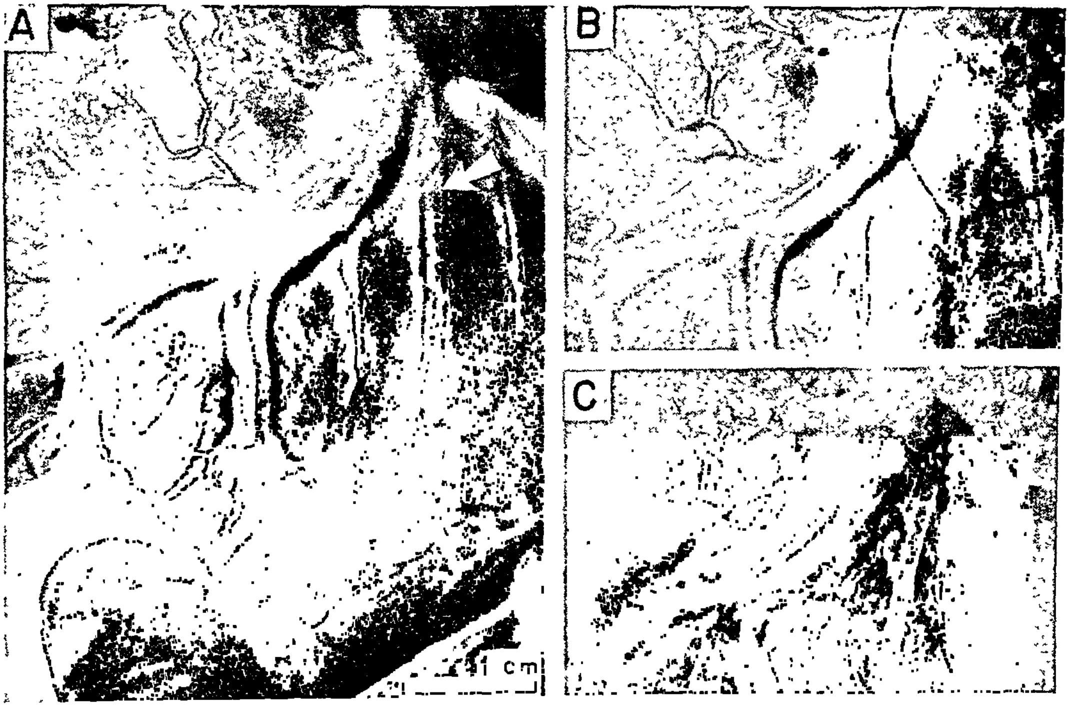

Fig. 1.—Photographs of stages in the cannulation of a coronary branch for arteriography in a dog.

A, Left surface of the heart showing upper portion of the anterior descending coronary artery, its branches, and accompanying veins close to the atrioventricular sulcus. The left auricular appendage is shown in the right upper corner of the photograph. At the left lower corner a gauze-covered finger makes downward pressure to expose the branch to be cannulated (*arrow*). *B* shows the coronary branch during its isolation and *C* the cannula tied into the vessel.

Tolerance to the injection of undiluted contrast material into the left coronary system was tested in three preliminary experiments by repeated injection of 10 c.c. volumes of Hypaque* while the exposed heart was kept under observation.

Angiograms were done in 18 dogs. In these experiments the polyethylene tube was led out through the pericardium and the sixth interspace anteriorly or posteriorly and the chest was closed for transfer of the animal to the X-ray Department.† The left chest wall was placed directly upon the x-ray cassette. Standard radiological equipment and x-ray film‡ were used. Ten cubic centimeters of contrast medium was injected rapidly by hand (3 to 5 seconds) using a 10 c.c. syringe and a one-meter length of wide tubing connected to the fine polyethylene tube. Just before completion of the injection the radiogram was taken at 46-60 kV., 400 mA., and 1/60 second. The focus to film distance was 90 cm. An intensifying screen was used, but no grid. One to 5 arteriograms were taken in each dog at intervals of 5 to 15 minutes, each exposure with a separate injection of contrast material.

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‡Eastman Kodak Blue Brand Film.

For stereoscopic views, additional arteriograms were taken with the tube moved 3 to 5 cm. horizontally.

A few serial angiograms* were taken with a rapid cassette changer and an impulse timer, using 90 kV., 700 mA., and 1.5 milliseconds. Up to 20 exposures were obtained at a rate of 3 per second, before, during, and just after the injection of contrast material.

The standard technique for a single angiogram prior to a procedure upon a coronary artery is completed by removal of the catheter and ligation of the incised branch. Most of the present experiments were terminated at this point. A number of the dogs were sacrificed at once and the hearts excised for detailed stereoradiographic study of the coronary pattern. The coronary arteries were injected with Micropaque (40 per cent suspension in 2.5 per cent solution of gelatin in water) introduced into the left coronary system through the cannulated branch after suture closure of the left coronary ostium, and into the right coronary system through a cannula in the right coronary ostium.

In a few experiments the tube was left in place, its outer end tied and covered with a dressing. The lumen was cleared with a small quantity of heparin at intervals ranging from 1 day to 1 week, and arteriograms were taken weekly. Aseptic technique was used whenever the experiments were to be carried beyond the day of cannulation.

Electrocardiographic recording was carried out during the cannulation and injection of contrast material in 7 dogs, and the myocardium was subsequently studied histologically for evidence of injury due to ischemia or chemical trauma. These tests were carried out with tube sizes PE 90 to 100.

RESULTS

The injection of three 10 c.c. doses of Hypaque in rapid succession produced no change in heart action in any of the 3 dogs tested except for a transitory slowing in the rate. A fourth injection given immediately thereafter led to ventricular fibrillation in 2 of the dogs.

The procedure was tolerated well in the angiographic experiments. Intervals of 5 minutes or longer were maintained between injections of contrast material and 17 of 18 dogs received 42 injections without evident ill effect. One dog died a minute or two after completion of an initial injection, probably of ventricular fibrillation. Anesthesia in this case had been maintained for something over 3 hours and there was evidence that the dog was anoxic at the time of injection.

Electrocardiographic observations demonstrated T-wave depression beginning 2 seconds after the start of the injection. By the end of the injection

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*We are grateful to Dr. Edward B. D. Neuhauser of the Children's Medical Center, ton, for permission to use the equipment of his department, and [illegible] Hammond his technical assistance.

(3 to 5 seconds) the T waves were strongly negative. At this time the heart rate slowed somewhat. Return toward normal began within 1 second after termination of the injection and was complete within 30 to 60 seconds. Similar changes were seen when physiologic saline solution was injected instead of Hypaque. Ventricular fibrillation terminated a series of injections in 2 of these electrocardiographic control experiments. In both cases, this occurred during a period of induced general anoxia, produced by reduction in pulmonary ventilation until electrocardiographic evidence of myocardial anoxia appeared. In one, the injection period was also prolonged. Defibrillation was readily accomplished by electric shock.

Hand injection of contrast medium through tubes smaller than PE 90 proceeded too slowly to provide the desired concentration within the coronary arteries. Although the medium was distributed well through the branches of the left coronary artery the photographic contrast was poor. Injection through tubes PE 90 to 100 was rapid enough to permit quite complete displacement of blood by contrast medium and no advantage was gained by using larger tubes. The sacrifice of a coronary branch just able to accommodate a PE 90 to 100 tube produced no color change on the surface of the heart in most experiments. In 2 dogs, the cannulated branch was unusually distant from neighboring branches and a small area of cyanosis appeared. The cyanosis had largely cleared by the time of closure of the pericardium. Cannulation produced no change in cardiac rhythm and only an occasional slight and transitory downward deflection in T wave. However, a small intramural infarct was usually found upon histologic examination of the tissue supplied by the sacrificed branch. The zone of myocardial injury did not in any case exceed 5 to 10 mm. in length and 3 to 5 mm. in greatest transverse diameter. Histologic examination of coronary vessels and myocardium away from the site of ligation showed no evidence of injury.

The post-mortem angiograms showed that the in vivo delineation of the left coronary system was complete within the size range of the branches demonstrated by the method (Fig. 3) and confirmed the localization and identification of the branches given by the in vivo stereo-angiograms. The smallest vessels clearly visualized in vivo measured 0.2 mm. in diameter in the post-mortem specimen.

The standard single-exposure arteriograms regularly showed extensive contrast filling of the left coronary system; the distribution of the circumflex and septal arteries being shown as well as that of the anterior descending coronary artery. Definition was good. Sometimes the vessel outlines, either at the apex or at the base of the heart, were not entirely sharp, but quite often the entire distribution of the left coronary artery was sharply visualized so that branches of the third order could readily be made out (Fig. 4). The pattern of the left coronary system was reproduced well in repeated angiograms, with some variation only in the extent of outlining of branches of the third order. The cannulated branch beyond the point of ligation was not visualized in the initial angiograms.

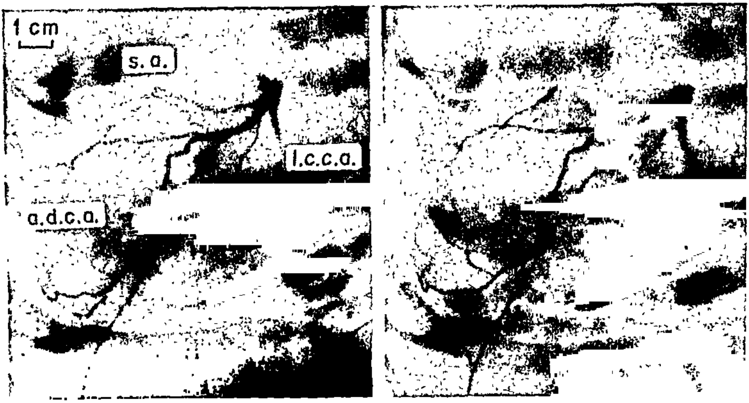

Fig. 2.—Stereoscopic coronary arteriograms reduced in size. The second exposure is obtained with a second injection of contrast medium.

The polyethylene cannula enters a small coronary branch; a slight blur of extravasated contrast medium in the region of dissection indicates the place of cannulation. The polyethylene tube runs in a loop in the left chest; it has moved slightly with the respiration of the animal between exposures and therefore gives a false impression of its depth location.

The left circumflex (*l.c.c.a.*), the anterior descending (*a.d.c.a.*), and the septal artery (*s.a.*) are indicated in the illustration. No contrast material is seen in the aortic bulb in either exposure and the right coronary artery is not visible.

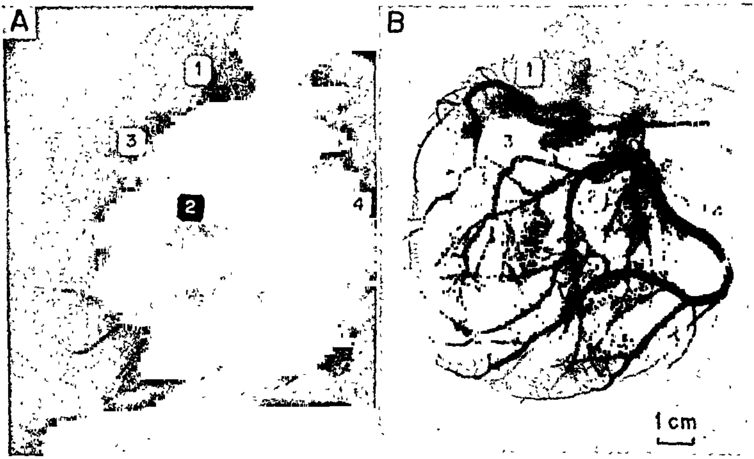

Fig. 3.—Coror [illegible] (*A*) and post mortem (*B*). The markers indicate the right coronary [illegible] or descending (*2*), septal (*3*), and circumflex (*4*) branches of the le [illegible] origin of the septal artery lies within the left coronary ostium. [illegible] tically across the heart in *A* has been cut short in *B*. A second ca [illegible] coronary ostium is seen in *B*.

The air-filled cavity of the right ventricle shows in *B* between the right coronary and septal arteries. The arch of the aorta may be seen, containing contrast material in *A* and air in *B*.

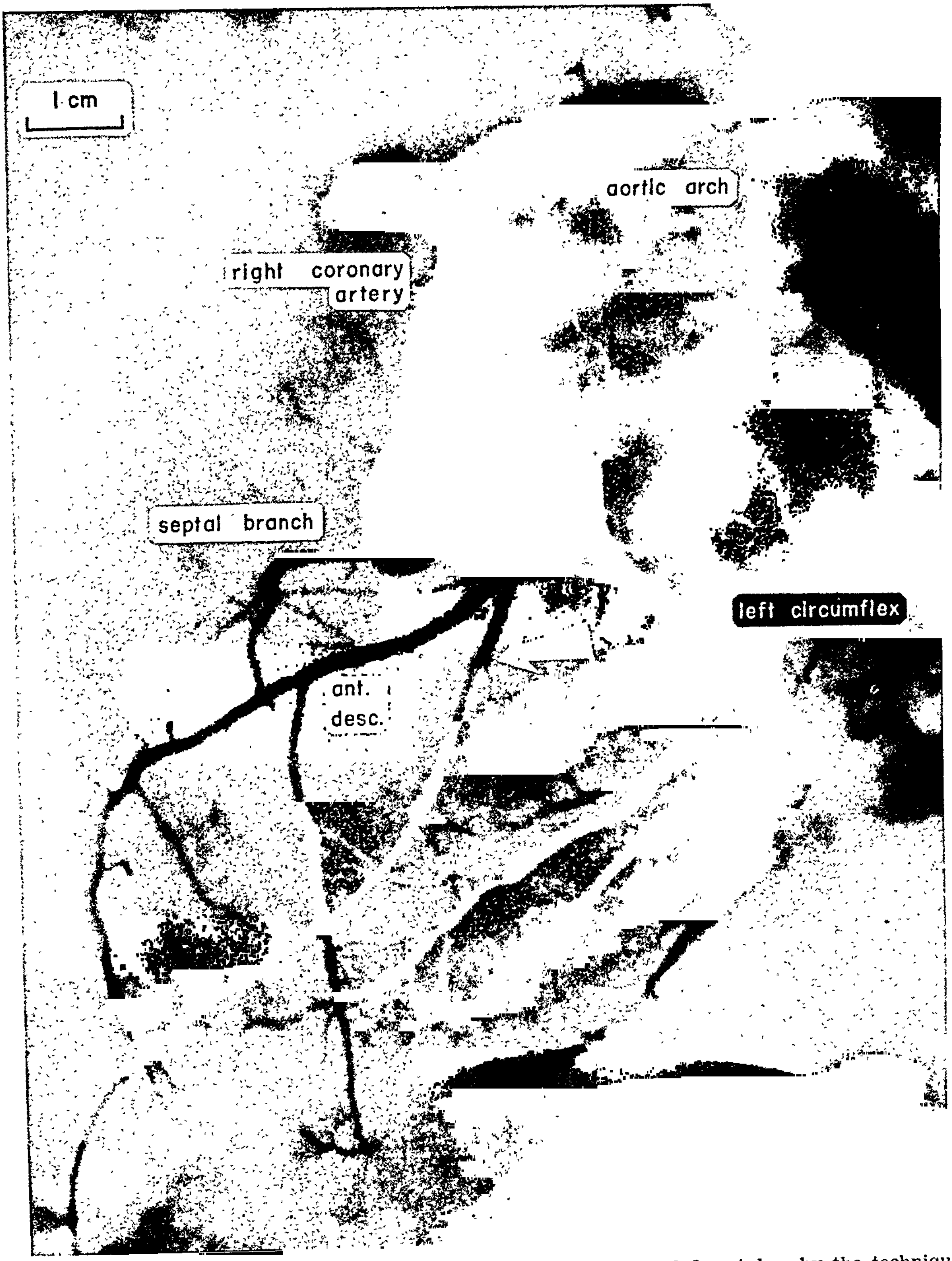

Fig. 4.—Coronary arteriogram, slightly enlarged, in a normal dog, taken by the technique described for single angiograms. The resolution is considerably greater than in the serial angiograms (Figs. 2 and 5). The heart is presented in lateral view with its left aspect toward the film. The site of insertion of the polyethylene tube at a point of subdivision of a coronary branch is marked by the arrow.

The contrast filling of the left coronary system is even. Arborizations of the third order to the ventricular myocardium can be distinguished; some atrial vessels are also seen. The right coronary artery and several of its arborizations are visible with low, somewhat uneven contrast. The cardiac veins are not outlined.

The aortic bulb is well filled with contrast material; all three sinuses of Valsalva are well outlined. The contrast is irregular in the arch of the aorta and its branches.

The contrast medium filled the proximal portion of the left coronary artery and jetted out into the aorta, sharply outlining the left sinus of Valsalva Serial angiograms demonstrated filling of the left coronary system by the first 2 to 3 c c of contrast medium Additional medium escaping into the aorta was washed away with each systolic ejection of blood from the ventricle so that, in individual exposures, the ascending aorta was frequently clear, while contrast medium and blood formed an irregular, swirling mixture in the aortic arch and in the descending aorta The thickness of the wall of the descending aorta

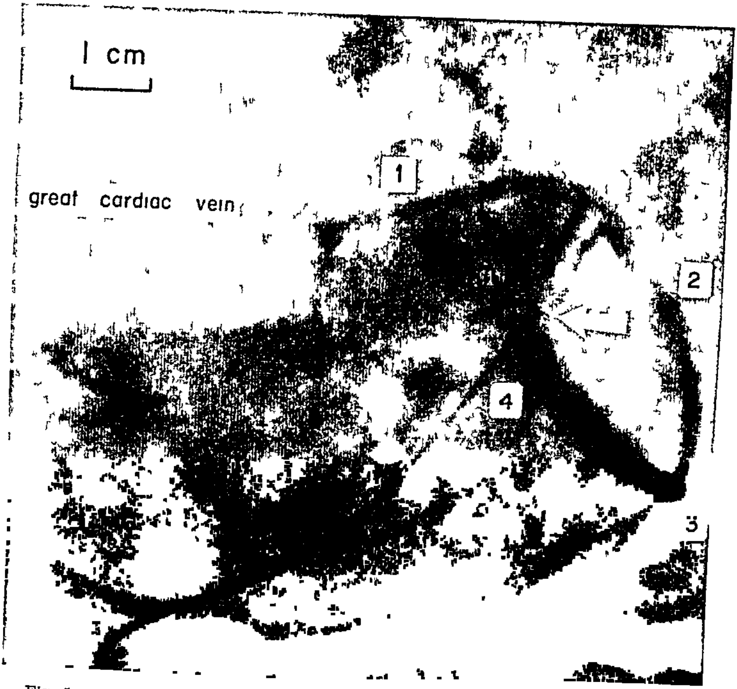

Fig 5—Venous phase of coronary angiogram (approximately natural size) Exposure 3 seconds after the end of the contrast injection in a series taken with an impulse timer and cassette changer

The polyethylene tubing still contains contrast medium but there is no remaining arterial contrast except in the small branch to the right and below the end of the tube (*arrow*) Partial occlusion by the tip of the tube apparently delayed the disappearance of contrast material from this branch

A first order venous tributary is seen on each side of the cannulated arterial branch (no longer visible but indicated by the end of the tube) These and similar venous tributaries enter the great cardiac vein which accompanies the anterior descending coronary artery on the anterior surface of the heart (*1*) then curves to lie transversely in the atrioventricular groove (*2*) follows the groove to the posterior aspect of the heart (*3*) and continues to the right to become the coronary sinus (*4*) The image of the coronary sinus is superimposed over that of the end of the tube Contrast material emerging through the ostium of the coronary sinus forms a sickle shaped shadow outlining the auricular wall

The photographic contrast in the venous phase of the angiogram is lower than that of arterial phase was shown by the width of the space between the column of contrast medium within the lumen and the negative shadow of periaortic fat and areolar tissue.

The right coronary artery was delineated to some extent in most arteriograms, but usually in discontinuous segments, in relation to the discontinuous entry of contrast medium from the root of the aorta. Even when the arborization of the right coronary artery was shown quite extensively, the photographic contrast was low (Fig. 4).

Cardiac veins were visualized in most single angiograms. Serial angiograms showed the first signs of venous delineation within 1.5 seconds of the start of the injection. Contrast filling of the veins increased during the remainder of the injection period, and persisted while the arterial contrast disappeared during the 2 or 3 seconds followed in serial radiograms after the completion of the injection. The main cardiac veins and their first and second order tributaries could be distinguished (Fig. 5), but photographic contrast was never as high as in the images of the arteries.

A faint haze due to capillary leakage often appeared in the area of dissection of the cannulated coronary branch, but this did not interfere significantly with the delineation of the vascular pattern.

When the catheter was left in situ, patency and free bleeding could be maintained without undue inconvenience for about 2 weeks. Then the last few millimeters of the tube became occluded by clot formation. Clotting did not extend into the vessel. The tube lumen could usually be cleared by the injection of saline, and the dislodged clot could then be identified in subsequent arteriograms as an embolus in the terminal distribution of the anterior descending coronary artery, unless the saline was injected sufficiently forcefully to eject the clot into the aorta. Clotting, undue embolization, or the development of leakage at the point of cannulation brought these experiments to an end. Repeated arteriograms during this period showed excellent reproducibility of the initial pattern apart from the small clots introduced. There was no evidence of thrombosis in consequence of the repeated injections of Hypaque and no visible collateral branches were stimulated by the procedure. The portion of the cannulated branch beyond the site of ligation could occasionally be seen in arteriograms taken after 1 week.

DISCUSSION

The surgical trauma involved in a direct approach to the heart for coronary angiography is no doubt greater than that of retrograde catheterization of the aorta. However, as stated at the outset, this method was developed for use in association with experimental procedures which in themselves require exposure of the heart. Suitable x-ray equipment in the experimental laboratory permits the taking of angiograms while the chest is open. Besides being convenient for decannulation, the open chest is an advantage in dealing with the occasional occurrence of ventricular fibrillation.

The introduction of contrast medium into the coronary vessels provoked slowing of the heart rate and T-wave changes, as has been observed during coronary angiography via the aorta. It is not certain to what extent this is a chemical injury or simply due to displacement of blood. The latter mechanism is suggested by the quite similar electrocardiographic changes we produced by injecting saline. However, even if the injection of Hypaque also introduced an element of chemical trauma, the electrocardiographic changes were transitory and no evidence of lasting damage was found on histologic study. Hypaque has been left within coronary arteries by others during periods of cardiac arrest exceeding 1 hour without evidence of harm.[20]

The main hazard of coronary arteriography appears to be the risk of producing ventricular fibrillation during or just after the injection of contrast medium. Systemic anoxia due to poor respiratory exchange, and local anoxia due to prolongation of the injection period undoubtedly increase this risk. The amount of contrast material injected and the period of displacement of blood from the left coronary system can be reduced; the serial angiograms showed optimal filling and contrast by the time 2 to 3 c.c. of contrast material had been injected. For successful single exposures with a small amount of contrast medium, the x-ray unit must be triggered by a mechanism synchronizing the exposure with the brief period of contrast filling of the vessels.[8]

The ligation of the coronary branch used for injection regularly caused some myocardial damage in spite of the extensive backflow noted at cannulation. These collateral connections apparently increased in function after the ligation, because the distal portion of the branch sometimes appeared in angiograms taken a week or more after cannulation, although the collateral vessels themselves never became large enough to be seen in in vivo angiograms. The sacrifice of a branch for cannulation is readily worked into an experiment on the development of coronary collaterals, but may otherwise be a disadvantage.

What recommends the method is the high quality of the angiograms obtained, using standard radiographic equipment. Single-exposure arteriograms delineated the coronary arterial vessels almost to the limit of naked-eye resolution, i.e., to 0.2 mm. in diameter, as measured in the post-mortem injection. There was little variation in the in vivo pattern visualized in repeated angiograms during a single sitting. The physical basis of the method gives reason to expect this reproducibility. The only variation observed was in branches at the limit of in vivo visualization; this was probably a variation in definition due to cardiac and respiratory motion rather than a true change in vessel diameter. Comparison of in vivo angiograms with the more detailed studies in the excised hearts gave further confidence in the reliability of the method. The injection of contrast material in itself did not provoke any change in vascular pattern or lead to the closing or opening of vessels of the size visualized.

Arteriography by retrograde injection through a distal branch depends upon the arterial pressure of the living animal to oppose backflow of contrast medium and ensure filling of the system under study. In a nonliving [illegible] the contrast material would flow through the injec[illegible] [illegible]ch and the st[illegible] sel and would then be dissipated into the aorta. [illegible]mal, [illegible] jection pressure must be sufficiently high to acc[illegible] [illegible] ment of blood by contrast medium and to prevent [illegible] column by jets of blood from the aorta. Some contrast medium is therefore lost into the aorta, but filling of all branches of the left coronary artery is ensured, including those which arise within the coronary ostium, as a large septal branch not infrequently does (see Fig. 3).

The present work was applied to the left coronary system. Some visualization of the right coronary artery was usually also obtained, but it was too fragmentary and unpredictable to be useful. However, if the major interest lies in the right coronary system, a branch of the right coronary artery can be selected for the injection.

The stereoscopic views were taken by successive exposures and did not always catch identical phases of injection, respiration, or cardiac action. These were not, therefore, true stereo-pairs in a photogrammetric sense. However, they could be viewed comfortably in a mirror stereoscope and the irregularities observed did not interfere with the identification of the vessels examined.

The method in general seems suitable for its intended purpose of delineating coronary arteries in association with experimental procedures requiring a direct approach to the heart. Its definition is sufficient, for example, to demonstrate the major vascular pattern prior to the application of a procedure designed to augment coronary collaterals. The method can provide repeated observations in vivo. It may be possible to utilize single angiograms of this kind clinically, in association with direct surgical procedures upon the coronary arteries, particularly if the branch used for injection can be saved by immediate removal of the cannula or needle or by the incorporation of that branch in the vascular reconstruction.

SUMMARY

A method is described for coronary angiography in the surgically exposed heart of the dog, using standard radiographic equipment. The method was designed to provide a detailed in vivo demonstration of the pattern of the left (or the right) coronary artery immediately prior to a direct experimental or surgical procedure upon the coronary vessels. The angiographic method was tolerated well. Coronary branches were reliably delineated down to third order divisions, corresponding to a diameter of approximately 0.2 mm.

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AORTO-ESOPHAGEAL FISTULA: A LATE COMPLICATION FOLLOWING INSERTION OF A HUFNAGEL VALVE

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THE exsanguination of a patient due to an aorto-esophageal fistula 22 months after insertion of a Hufnagel valve warrants attention being directed to this complication. Since the initial report of Hufnagel,[1] this type of prosthesis has been utilized in numerous clinics to palliate the sufferings of a patient with severe aortic insufficiency. Several complications have been recognized incident to this procedure and include septicemia, aneurysm formation at the site of aortic transection, and embolism secondary to thrombosis in proximity to the prosthesis.

The following case report describes a delayed complication not heretofore noted.

CASE REPORT

C. A., a 32-year-old white man, entered the University of Kansas Medical Center on April 23, 1954, with a heart murmur first discovered in 1938. There was no definite history of rheumatic fever.

He had been well until August, 1948, when he had an upper respiratory infection followed by recurrent episodes of weakness, fever, a productive cough, a sense of tightness in the upper chest, headache, anorexia, and night sweats. These symptoms caused his admission to the Veterans Hospital in Los Angeles in 1949.

The physical findings and his subsequent hospital course were compatible with subacute bacterial endocarditis superimposed on rheumatic heart disease. He was maintained on massive antibiotics (penicillin, streptomycin, and Aureomycin) for 13 weeks. At the time of dismissal he complained of mild dyspnea and a pressing substernal pain radiating down both arms.

He was readmitted in 1950 because of recurrent febrile episodes. From 1950 to 1952, he was relatively asymptomatic. In 1952, he had attacks of giddiness and syncope, resulting in loss of consciousness. Episodes of substernal and precordial chest pain radiating to the neck and the ulnar distribution of the left arm became more frequent. These pains were variously described as sharp, dull, or "pressure-like." They were unrelated to exertion, occurred frequently at night, and were not relieved by nitroglycerin. Ankle edema was noted during the several months previous to hospitalization in 1954.

Physical examination, when admitted to the University of Kansas Medical Center in 1954, disclosed a blood pressure of 154/40 mm. Hg. The heart had a normal sinus rhythm and was enlarged to the left with a diffuse apical impulse in the fifth interspace at the anterior axillary line. Over the aortic area a Grade II systolic thrill was palpable, and a Grade IV harsh systolic and a Grade III diastolic murmur could be heard. These murmurs were transmitted over the entire precordium and were of Grade II intensity at the apex. There was a Corrigan pulse. The lung fields were clear to percussion and auscultation. The liver was palpable 3 cm. below the right costal border and was not tender. No ankle edema was noted.

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Fluoroscopy showed the heart to be enlarged, and "boot shaped" with marked hypertrophy of the left ventricle and a clearance angle of over 90 degrees Electrocardiograms showed left ventricular hypertrophy Other routine laboratory studies were within normal values including tests to determine rheumatic activity

Because of the patient's incapacity and the progress of his symptoms during the past several years a Hufnagel procedure was advised This was done on April 30, 1954, with occlusion of the thoracic aorta for 7 minutes and 50 seconds He tolerated the operation well and was dismissed after an uneventful recovery for further convalescence in the Veterans Administration Hospital His only complaint was that of incisional pain, apparently distinct from the angina previously noted

Postoperatively, a decrease in the heart size was noted (Fig 1)

The episodes of weakness and syncope decreased markedly Following dismissal from the Veterans Hospital the patient returned to work where he drove his own truck and managed a fruit market

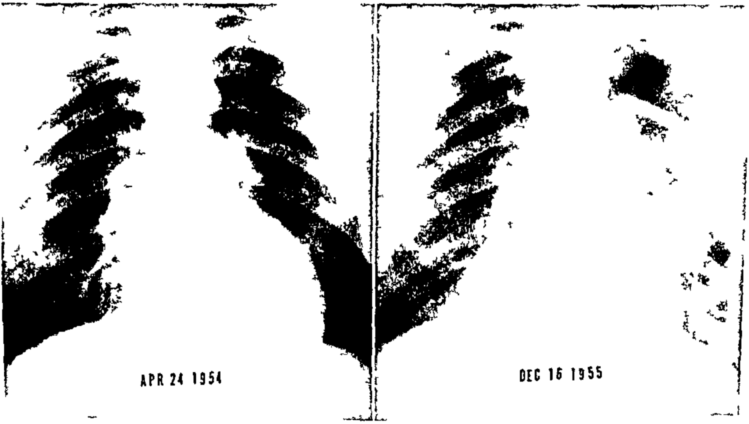

Fig 1—Chest roentgenograms before and after insertion of the Hufnagel valve Note particularly the obvious reduction in heart size postoperatively and the mediastinal shadow in the area of the Hufnagel valve insertion

The chest pain recurred, however, and was described by the patient as a feeling of pressure from the substernal area radiating down to both elbows It was not relieved by nitroglycerin

He was readmitted to the Kansas City Veterans Administration Hospital on Feb 2, 1955, because of fever of 103° F and chest pain Blood studies disclosed a hemoglobin of 8 6 Gm per cent and a white cell count of 15,000 He was placed on various combinations of antibiotics and Benemid which did not result in clinical improvement, and subsequently were changed to Terramycin, erythromycin, and massive doses of penicillin During several weeks the temperature gradually decreased to normal One blood culture was positive for hemolytic staphylococci The previous complaint of pain persisted but was controlled by the oral administration of codeine or Demerol He was dismissed on May 11, 1955

From May until December he was able to work but was again hospitalized on December 15 with complaint of pain along the right costal border This pain did not occur with exertion and was constant in severity and occurrence No dyspnea accompanied it, and the comfort did not suggest angina It was managed by phenobarbital, Reserpine, and t casional use of narcotics

On Jan. 26, 1956, he was admitted to the hospital for the last time with a history of a severe pain for 5 days at the upper end of his sternum, radiating inferiorly. This had increased in frequency and severity, and was associated with dyspnea, nausea, and vomiting.

Physical examination disclosed an acutely ill patient with a temperature of 100° F., a white cell count of 11,800, and a hemoglobin of 13.6 Gm. per cent. A roentgenogram of the chest showed no changes from those noted in previous years. For the next 6 days he remained febrile and was given penicillin. Subsequently the pain in the chest increased and radiated to the mid-dorsal and lumbar areas, and to the right side of his chest. On Feb. 19, 1956, his fever increased to 103° F. and was accompanied by upper abdominal pain. During the next 10 days he received penicillin and streptomycin. The severe pain in the lower part of his chest and upper abdomen persisted, accompanied by abdominal cramping and distention. Over the course of the next 3 weeks the pain gradually disappeared and for several days he was relatively asymptomatic. On March 5, 1956, he had massive hematemesis treated by the administration of blood and dextran. A few hours after the first hemorrhage he had a second massive hematemesis and died, 22 months after insertion of the plastic aortic valve.

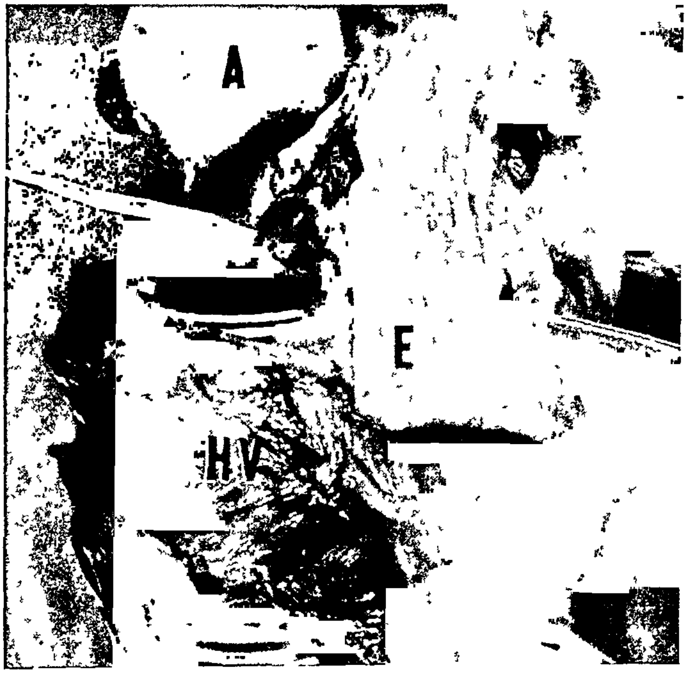

Fig. 2.—Photograph of gross specimen showing the aorto-esophageal fistula and the esophageal ulceration *A*, aorta; *E*, esophagus; *HV*, Hufnagel valve.

*Post-mortem Examination.**—No free fluid was noted on opening into the pleural cavities. The pericardial sac was intimately adherent to the epicardium. At the first portion of the descending thoracic aorta a prominent mass was noted attached to the esophagus and trachea. Examination of the intestinal viscera showed them to be distended by dark blood. No other abnormalities of the abdominal viscera were noted.

The heart was removed in toto with the aorta, trachea, and the esophagus. It was grossly hypertrophied. The coronary arteries appeared normal.

Examination of the interior of the heart showed a shiny endocardium with rather marked hypertrophy of the papillary muscles and the trabeculae carneae of the left ventricle and to a lesser degree of the right ventricle. The cusps of the aortic valve were sclerotic, thickened, and calcified, although the sinuses of Valsalva and the coronary orifices were normal The myocardium of the left ventricle measured 16 mm and that of the right 4 mm in thickness The circumferences of the valves were tricuspid 14 cm , pulmonic, 7 5 cm , mitral, 10 5 cm , and the aortic, 7 cm

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*I am indebted to Dr. James A. Turner, Chief, Laboratory Service, Veterans Administration Hospital, Kansas City, Mo., for performing the post-mortem examination and interpreting the microscopic findings

The aorta was dissected free from the previously described mass Its elasticity was well preserved without visible areas of atheromatosis The Hufnagel valve was present in the first portion of the descending aorta although it had completely lost its attachment proximally with the aorta Its attachment with the aorta distally was intact A thick fibrous membrane connected the proximal and distal portions of the aorta and enveloped the valve Upon opening the esophagus, several large areas of ulceration at the level of the prosthetic valve were noted (Fig 2) One of the ulcerations had perforated to communicate with the space between the valve and its fibrous covering Here clotted blood and partially organized thrombi were found Below the level of the prosthesis the aorta appeared normal

The lungs revealed a small amount of clotted blood in the bronchi and bronchioles The parenchyma was well aerated and elastic with a normal appearance of the major blood vessels

Microscopic examination of the aorta disclosed a fistulous tract partially filled by laminated thrombus, surrounded by proliferating fibroblasts A moderate amount of athero sclerosis and adventitial inflammatory reaction was noted Evidence of old hemorrhage was indicated by hemosiderinophages Sections of the heart and aortic valve showed endocardial thickening mild interstitial fibrosis of the myocardium and fibrocalcific changes in the valve leaflets

COMMENT

It appears most likely that this patient developed a false aneurysm at the proximal point of insertion of the Hufnagel valve This might have occurred as a direct result of weakening of the aortic wall due to erosion of the rigid prosthesis A second possibility is a smoldering infection in this region with abscess formation and fistulization to the esophagus The repeated febrile bouts postoperatively suggest an inflammatory process although the microscopic evidence did not confirm this

The benefit obtained by this patient for the early part of his postoperative course was considerable and enabled him to be employed gainfully He also remained free from congestive heart failure

Experiences with the Hufnagel type of prosthesis have been widely divergent Due to the far advanced heart disease of the patients for whom this is advised and the postoperative complications, the procedure carries a significant mortality and morbidity The long term results of those who survive however have in most instances been judged as excellent to good As stated by Bland and Wheeler" in their account of 14 patients, "Thus, our experience with the artificial valve has been satisfactory in 40 per cent of a small series of 14 patients In a few the results have been remarkable to an extent that has encouraged us and others to accept and to advise this physiologic compromise for those in serious difficulty until a more promising procedure is available "

Our own small series of 10 patients is summarized in Table I Particular attention should be noted to patients 3, 8, 9, and 10 The first is living, well, and working daily as a farmer The next patient successfully completed a full term pregnancy without difficulty while the last 2 patients are relieved of th

ous symptoms of congestive failure That such an unfor mpl

an aorto esophageal fistula may occur 22 months after

must be evaluated in assessing the risk of this p

TABLE I

CASE NO.	INITIALS	SEX	AGE	DIAGNOSIS	DATE OF OPERATION	RESULTS
1	K. R.	M	30	Rheum. H.D.	April, 1954	Uremic preoperatively; died renal failure on 2nd postop. day
2	B. G.	M	33	Rheum. H.D.	April, 1954	Died 21st day postop. of septicemia
3	R. M.	M	62	Rheum. H.D.	May, 1954	Living and well; works daily as farmer
4	C. Z.	M	23	Rheum. H.D.	July, 1954	Died during anesthetic induction
5	R. S.	M	63	Syphilitic H.D.	July, 1954	Died 16th day postop. from mesenteric embolus
6	B. W.[3]	M	33	Marfan's D.	March, 1955	Died 4 months postop.
7	C. M.	F	44	Syphilitic H.D.	March, 1955	Good result, but died 7 months postop. from empyema of gall bladder
8	C. G.	F	19	Rheum. H.D.	April, 1956	Living and well; had full-term normal pregnancy
9	M. H.	F	50	Rheum. H.D.	Sept., 1956	Living and well
10	R. T.	M	21	Rheum. H.D.	Dec., 1956	Living and well; working daily

satisfactory method can be devised for the direct correction of aortic valvular deformity or for the insertion of a new competent aortic valve of some type, the Hufnagel prosthesis appears to offer appreciable palliation for the patient with severe aortic insufficiency.

SUMMARY

1. A 32-year-old white man with severe aortic insufficiency due to rheumatic heart disease was subjected to operation with insertion of a Hufnagel type of prosthetic valve. Appreciable objective and subjective benefit resulted postoperatively.

2. Twenty-two months postoperatively, after 5 days of acute illness, he suddenly died with massive hematemesis from an aorto-esophageal fistula at the proximal site of the prosthetic valve insertion.

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RESECTION OF CARCINOMA OF THE MID-THORACIC ESOPHAGUS WITH PRIMARY ANASTOMOSIS

A Report of 4 Cases, and One 9½-Year Cure

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It is common knowledge that the prognosis for carcinoma of the esophagus above the cardia approaches zero. So true is this that one well known esophageal surgeon has stated jokingly that if he were afflicted with the disease, he would insist only on periodic dilatations to ensure the steady flow of ethanol from his pharynx to his stomach.[1] At Johns Hopkins there has never been a 5 year survival regardless of the level of the lesion.[10] In 1954, the dean of esophageal surgery, Sweet, reported 145 cases of mid thoracic carcinoma followed for 5 years with only 2 survivors.[18] Other reports attest to the inadequacy of surgical methods in effecting significant cures.[9, 10, 12, 13, 16, 17] Actually the most encouraging results have been reported by the radiologists,[1, 3, 4, 11, 17] but even with superior statistics they have demonstrated consummate reluctance in suggesting that they should therefore assume this problem.

It would be repetitious to enumerate the fundamental anatomic facts which render carcinoma of the mid esophagus hopeless. One has only to glance at a cross section of the thorax to realize that an adequate cancer operation is impossible. The cure of the individual carcinoma of the mid thoracic esophagus is a matter of luck. The management of the individual case is an exercise in common sense.

With this in mind we were attracted to the idea of restoring continuity by the simplest and least traumatic surgical means: primary anastomosis. Such a technique obviously limits the extent of resection and is, therefore, subject to the criticism of disregarding submucosal spread.[14] Conversely, it may be argued that those patients with submucosal extension are already beyond the curative stage and that therefore a palliative procedure to restore deglutition promptly is the therapy of choice.

In any event, the following descriptions represent our experience with this operation.

CASE REPORT

Case 1.—A 56 year old white housewife was admitted to the Harrisburg Hospital on May 18, 1948, with the chief complaint of dysphagia. She stated that for 15 months she had had progressive difficulty in swallowing solid foods although liquids gave her no trouble. The food stuck about halfway down and was regurgitated undigested in a few minute

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Her general health was otherwise good and she had no significant complaints. She had a good appetite. Her past medical history revealed that in 1934 she had undergone a left simple mastectomy for chronic cystic mastitis, and a supravaginal hysterectomy for fibroids. In 1939, the right breast was amputated for cystic mastitis. The family history was noncontributory.

On May 21, 1948, esophagoscopy demonstrated a mid-esophageal bleeding friable tumor, biopsy of which was diagnosed as a Grade III squamous-cell carcinoma. The red cell count was 4.22 million per cubic millimeter, white cell count 5,700 per cubic millimeter with a normal differential count. Hemoglobin was 12.6 Gm. or 84 per cent. Urinalysis was normal, except for a trace of albumin.

On the fourth of June, a left thoractomy was performed through the periosteal bed of the resected sixth rib. The lung was not adherent. On exposing the esophagus, a hard nodular lesion approximately 2 inches long just below the region of the aortic arch was encountered. There were two adjacent lymph nodes. A primary anastomosis was effected with two rows of interrupted sutures of nylon, but this was under considerable tension. A Levin tube was passed through the nose past the anastomosis into the stomach. Fibrin foam was placed around the anastomosis and the chest was closed in layers after an intercostal catheter had been brought out through a stab wound.

The pathologic report on the surgical specimen confirmed the endoscopic biopsy report of squamous-cell carcinoma. In addition, one of the adjacent lymph nodes contained metastatic epithelioma. Grossly, the tumor was described as ulcerated, friable, and circumferential.

Postoperatively her course was complicated by the development of an esophago-pleurocutaneous fistula which was quite evident on the tenth postoperative day. The Levin tube which had been removed on the ninth day was re-inserted and penicillin resumed. From the twenty-fourth postoperative day, she was afebrile and was discharged 34 days after operation eating a full diet with but slight difficulty. She weighed 80 pounds.

In the 6 weeks that followed, this dysphagia progressed. Although it was necessary to re-admit her to the hospital on Aug. 26, 1948, she had gained 12 pounds. Esophagoscopy the following day revealed a granular stenosis at the operative site, but a No. 18 Fr. dilator was passed. Subsequently esophageal dilatations were performed upon her as an outpatient, but the stenosis progressed. On Nov. 22, 1948, a Witzel gastrostomy was performed under Pentothal sodium and nitrous oxide anesthesia. She gained weight but was chronically ill in spite of the fact that she could swallow soft foods without difficulty.

On Oct. 14, 1949, a left lower lobectomy was performed for a lung abcess secondary to a bronchoesophageal fistula. Her recovery was uneventful. Subsequently she gained weight, and although periodic esophageal dilatations were necessary, she had little trouble. On April 16, 1951, a No. 28 Fr. dilator was passed without difficulty. Eighteen months later routine esophagoscopy revealed no difficulty and only slight stenosis (Dec. 23, 1952).

In the ensuing years she has been asymptomatic. She eats a full diet without difficulty. Yearly esophageal checks have been normal, except for dilatation of a mild stenosis at the last esophagoscopy on Dec. 12, 1957. The last esophagogram in July, 1956, was normal except for two traction diverticula. X-ray studies of the chest were negative.

She is alive, relatively asymptomatic and well in December, 1957, 9½ years after esophageal resection with primary anastomosis.

Few authors have discussed primary anastomosis for carcinoma although it is the accepted method of restoration for children with congenital stenosis.[7, 8] In 1949, Parker and Brockington[11] reported 2 cases done for palliation; one patient lived 9 months. They demonstrated in dogs, moreover, that the technique with extensive mobilization is feasible.[11] In our patient operated upon, in 1948, anastomosis was accomplished with very little attempt at mobilization. This resulted in considerable anastomotic tension and indubitably accounted for the postoperative complications.

In October, 1956, we performed a similar operation through the right chest for a carcinoma at the level of the aortic arch. Unfortunately the patient had a metastatic mass involving the hilum of the right lung and mediastinum, which was left *in situ*. By mobilizing the esophagus extensively, however, we were able to make a two layered nylon anastomosis without tension. Except for a temperature rise to 100° F. on one occasion within the first 24 hours, the recovery was completely afebrile and uneventful. The patient was eating a full diet without difficulty on the eighth postoperative day. Subsequently, esophagoscopy was performed twice and although there was moderate stenosis and granulation tissue at the anastomosis he ate a soft diet without effort. A No. 28 Fr. bougie was passed easily on May 7, 1957. Biopsies on two occasions were negative for a recurrence of the neoplasm. The patient died elsewhere in July, 1957, apparently as a result of his disease.

When this was the extent of our experience with primary anastomosis after resection, we were understandably encouraged and wondered why such a simple procedure was not the standard one. Our ardor was quickly dampened and our question soon answered by the next 2 patients who died postoperatively. One patient had a frank disruption of the anastomosis and died from mediastinitis. The other had only a small leak from the anastomosis and there was no interference of the blood supply in spite of the fact that we had mobilized the esophagus from the cervical region to the diaphragm. The cause of his death is obscure because the mediastinitis was not overwhelming. In both of these cases the anastomoses were very difficult to complete because of the tension despite almost complete esophageal mobilization.

It is impossible to draw logical conclusions from 4 cases. We consider Cox's attitude on this subject to be both humble and intelligent. He states: "The object of the surgeon must be, therefore, to restore to the patient ease of swallowing for as long as he can contrive. If by doing a good operation in a favorable case he achieves a long term cure so much the better, but his attention must, I submit, be focused on restoration of function as an objective of prime importance." Therefore, we suggest that this method might be tried for palliation in a larger series by those who have access to more cases. We would recommend, however, that if an anastomosis without tension cannot be fashioned, another type of reconstruction, i.e., Berman tube[7] or esophagogastrectomy, be employed.

SUMMARY

To summarize, we have one patient with an apparent 9½ year cure following resection with primary anastomosis for squamous cell carcinoma of the mid esophagus with metastasis. She had a stormy course with complications requiring treatment for 2½ years postoperatively. The second patient, operated upon for palliation, had a completely uneventful recovery and no dysphagia until he died 9 months postoperatively. Two other patients died on the fifth and sixth postoperative days.

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TUBERCULOUS FISTULA OF THE ESOPHAGUS

Two Cases Successfully Treated by Surgery

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THE SUBJECT of tuberculosis of the esophagus has been reviewed by a number of writers[1-6] It is an extremely rare disease which may reach the organ by mucosal hematogenous or, most frequently, lymphatic routes By the latter means, disease in adjacent structures such as lymph nodes, pleura, and vertebrae may spread to the esophagus Fistulas between the esophagus and neighboring structures may occur as a result of contiguous infection Often the occurrence of a fistula is preceded by the formation of a traction diverticulum of the esophagus Generally the prognosis of untreated tuberculous esophagitis is poor, especially if stricture or esophagotracheal fistula exists Antituberculous drug therapy will cure some of these patients[7,8] Surgery, except gastrostomy, has been employed rarely with varying results It is the purpose of this communication to present 2 cases of tuberculous esophageal fistula which required surgery to effect a cure

CASE REPORTS

CASE 1—R M, a 48 year old white man, was admitted to Ray Brook on Jan 27, 1955 In July, 1950, following injury to his chest he had developed a right pleural effusion He received streptomycin for 20 days and para aminosalicylic acid for 6 weeks, after which he terminated treatment against the advice of his physician In March 1952, he entered a hospital, where he stayed for about 2½ months While in the hospital, he received streptomycin and para aminosalicylic acid In November, 1953, a diagnosis of tuberculous empyema was made after his admission to another institution Treatment there included streptomycin and isoniazid, systemically, and streptomycin, penicillin, Tryptar, and Varidase, intrapleurally On April 7, 1954, a right pleuropneumonectomy was performed This was complicated by a bronchopleurocutaneous fistula On Nov 10, 1954, an 8 rib right thoracoplasty was performed However, a pleurocutaneous fistula persisted until the patient's admission to Ray Brook Tubercle bacilli were last identified in the sputum on June 1, 1954

After admission to Ray Brook the patient's chest wall sinus was injected with iodized oil revealing an empyema pocket connecting with the stump of the right bronchus No connection with the esophagus was demonstrable Repeated cultures of sputum and empyema failed to yield tubercle bacilli *Staphylococcus albus* and *Escherichia coli* were cultured from the empyema

Following his admission, streptomycin 1 Gm 3 times a week and isoniazid 300 mg a day were administered until Feb 7, 1957 Early in September, 1955 the patient began to experience severe coughing and choking episodes following meals Careful questioning

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From the Ray Brook State Tuberculosis Hospital Ray Brook N Y
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of the patient revealed that these symptoms had not been experienced previously. An esophagram was performed revealing a small traction diverticulum of the upper esophagus communicating by a fistula with the right pleural cavity (Fig. 1, *A*). On Oct. 18, 1955, a bronchoscopy and esophagoscopy revealed a 1 to 2 mm. dimple at the right bronchial stump and, approximately, a 4 mm. opening on the right side of the esophagus, 26 cm. from the upper incisor teeth. When the patient coughed, bubbles of air came from the opening. No other abnormalities were noted.

On Oct. 21, 1955, a modified Schede thoracoplasty was performed on the right side. The external opening of the sinus tract together with the old thoracoplasty scar were excised. The subscapular space was opened and pus and debris were removed. This space communicated with the underlying pleural space by a fistula. Regenerated ribs from the second through the eighth and a part of the ninth rib were removed subperiosteally. The thickened parietal pleura was excised preserving as many of the intercostal bundles as possible. The pleural cavity was then filled with isotonic saline solution and intratracheal positive pressure was developed by the anesthetist. No bronchial fistula could be identified. The stump of the right main bronchus had apparently healed spontaneously. The esophageal fistula was identified, but it was inaccessible in the apex of the pleural space. Attempts to free the esophagus were unsuccessful because of extensive scarring. Accordingly, the wound was closed in layers about a soft rubber drain. Pathologic diagnosis of tissue removed at operation was chronic granulation tissue.

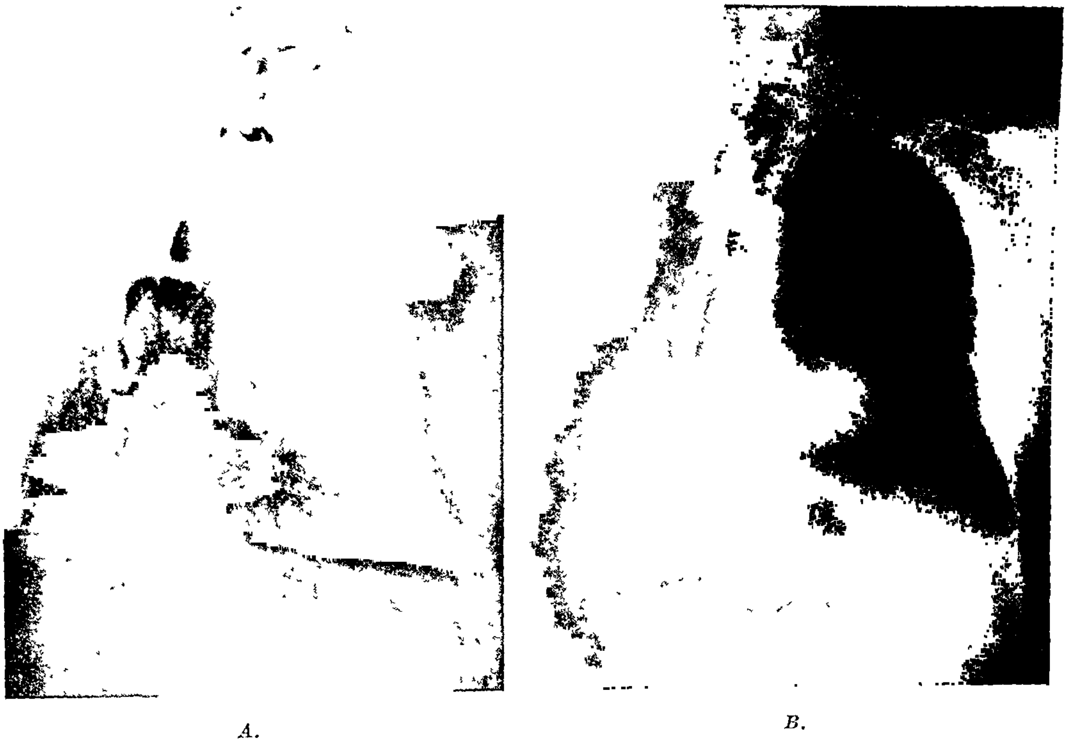
A. *B.*

Fig. 1.—Posteroanterior chest roentgenograms after the patient had swallowed radiopaque material. *A*, Shows outline of the esophagopleurocutaneous fistula. *B*, There is no evidence of fistula following surgical treatment.

On Oct. 26, 1955, a Witzel jejunostomy was performed. Following this the patient took nothing by mouth. The pleural space was allowed to heal from the depths outward. On Sept. 10, 1956, a small residual pleural pocket was obliterated by removal of several regenerated ribs with thickened parietal pleura and a partial scapulectomy. The drain was gradually shortened and the wound healed completely by January, 1957.

In January, 1956 an esophagram with iodized oil failed to reveal an esophageal fistula This was later confirmed by a barium swallow (Fig 1, *B*) Soon afterward the patient was able to take a regular diet without difficulty At the end of the month the jejunostomy tube was removed The patient was discharged from Ray Brook on May 7, 1957 In January, 1958, he reported that he had experienced no further complaints referable to his esophagus

CASE 2—J M, a 26 year old white man, was admitted to Ray Brook for the third time on Feb 3 1956 with fever and a tender swelling above the right iliac crest posteriorly When he was 2 years old a kyphosis was discovered In 1950, at 20 years he developed coughing episodes after eating or drinking By November, he began to experience fever In January, 1952, a swelling appeared over the right iliac crest posteriorly This soon opened spontaneously and drained purulent material This together with an abscess in the right groin was drained surgically in February, 1952 As tubercle bacilli were recovered, the patient was given streptomycin and para aminosalicylic acid therapy, which was continued until July 30, 1953 The patient was admitted to Ray Brook for the first time from March 26, 1952, to Aug 17 1953, because of recurrence of drainage from the iliac sinus This healed spontaneously, and remained healed until 2 weeks prior to the patient s second admission to Ray Brook (Nov 23 1955 to Dec 1, 1955), when he developed fever and tenderness at the site of the scar in the iliac region Symptoms [illegible] of inflammation subsided following needle aspiration of purulent material However remission was only temporary, and a recurrence of symptoms soon necessitated the third admission (Feb 3, 1956) Shortly afterward the sinus reopened, again draining purulent material

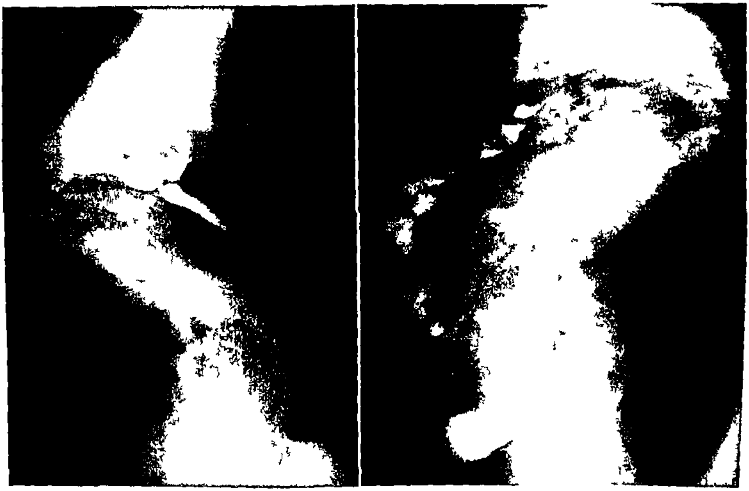

FIG 2—Lateral chest roentgenograms following ingestion of barium showing preoperatively (*A*) a traction diverticulum of the upper thoracic esophagus and postoperatively (*B*) an outline of the substernal colon bypass The patient has a severe dorsal kyphosis due to Pott s disease

Examination at this time revealed an acutely ill patient with a [illegible] kyphosis Except for a draining sinus in the right iliac region and a healed [illegible] the right groin there were no relevant findings on physical examination. Repeated cultures of the sputum and pus from the sinus failed to reveal tubercle bacilli. During each of the patient's admissions to Ray Brook, esophagrams revealed a large diverticulum in the region of the kyphosis (Fig. 2, *A*). There was a delay in emptying of the diverticulum and a suggestion of a stricture below the diverticulum. Careful questioning of the patient revealed that he experienced dysphagia only occasionally when he would swallow a large bolus of food. During the third admission, a connection between the diverticulum and the sinus was demonstrated by injecting iodized oil into the latter.

During the third admission the patient experienced recurrent episodes of fever accompanied by pain in the region of the sinus tract, which continued to drain. In order to defunctionalize the esophagus, a Stamm gastrostomy was performed on Jan. 7, 1957. On Feb. 20, 1957, the cutaneous fistula was excised down to the esophageal diverticulum. The wound healed rapidly and completely from the depths outward. However, as soon as tho patient was again permitted to take his feedings orally, the sinus reopened. On the other hand, as soon as gastrostomy feedings were resumed the sinus healed and remained healed as long as the patient took nothing by mouth. Since the patient did not wish to accept a permanent gastrostomy it was decided to permanently defunctionalize the esophagus by utilizing the colon as described by Mahoney and Sherman.[9] Accordingly, on June 26, 1957, the right colon and part of the transverse colon were transplanted into a substernal tunnel and, after the cervical esophagus had been severed a short distance below the cricopharyngeus muscle, the proximal esophagus was anastomosed to the cecum employing 2 layers of interrupted 4-0 silk sutures. The distal esophagus was closed by interrupted sutures of the same material and dropped back into the mediastinum. The esophagus was not severed near the cardia. The proximal end of the severed transverse colon was anastomosed to the anterior aspect of the stomach and the distal end to the proximal end of the severed ileum. Postoperatively, suction was maintained on the gastrostomy tube until gastrointestinal function returned. There were no complications. At the time of his discharge from the hospital on Sept. 2, 1957, the patient was able to take a regular diet without difficulty. Barium swallow revealed widely patent anastomoses (Fig. 2, *B*). There was no regurgitation of barium from the stomach into the defunctionalized lower esophagus when the patient was placed in approximately a 45-degree Trendelenburg position. In December, 1957, the patient reported that he had been able to return to work and had maintained his weight. He had experienced no difficulty referable to his new "esophagus" or wound in his back.

DISCUSSION

It might be argued that the fistula in the first patient was due to trauma at the time of resection of the right lung. However, the late appearance of symptoms referable to the esophagus and the presence of a traction diverticulum seem to indicate that infection was the principal etiological factor. Both traction diverticula and sinuses frequently occur in the upper thoracic esophagus as a result of adjacent tuberculous adenitis. In the second patient, Pott's disease undoubtedly preceded the formation of the esophageal diverticulum and probably was the etiological factor for this as well as the fistula. Tuberculous esophagitis secondary to Pott's disease has been reported.[4]

The role of antituberculous drug therapy in both cases was undoubtedly very important, since in both patients the tuberculous disease had become inactive by the time surgery was performed.

Excision of the fistula was unsuccessful in the second patient probably because of poor drainage of the diverticulum as a result of partial obstruction of the esophagus below that level On the other hand, in the absence of obstruction, healing of the fistula occurred rapidly in the first patient as soon as the empyema was successfully treated

Combined antituberculous drug therapy is likely to render tuberculous lesions of the esophagus inactive The lesions may heal with drug therapy alone, others require surgery to correct residual mechanical factors, such as fistula or stricture When surgery is indicated radical extirpation is rarely, if ever, necessary Every effort should be made to preserve the function of the esophagus by such methods as dilatation of strictures or local resection of symptomatic diverticula When the latter methods are not possible because of severe scarring or inaccessibility, as in the second case, a defunctionalizing operation may be used, leaving the excluded esophagus in situ It is not believed necessary to interrupt the lower esophagus near the cardia, as was done by Johnson and associates,[10] as long as the lower esophageal occlusion mechanism is competent and can prevent regurgitation of gastric contents Indeed, preservation of the continuity of the esophagus with the stomach permits internal drainage of the esophagus thus obviating, at least theoretically, the possibility of infection in a totally excluded segment of esophagus

SUMMARY

Two cases of tuberculous fistula of the esophagus treated by surgery are presented Tuberculous esophagitis and its complications will sometimes heal with antituberculous drug therapy alone However, surgery may be necessary to correct mechanical factors, in which cases every effort should be made to preserve as much esophageal function as possible Occasionally, it may be necessary to create a bypass Under these circumstances it does not seem necessary to extirpate the diseased organ

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CONGENITAL TRACHEOESOPHAGEAL FISTULA IN THE ADULT

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CONGENITAL tracheoesophageal fistula without atresia of the esophagus is a rare anomaly. In a review of pediatric cases, published by Ware and Cross in 1954, 27 cases were reported. In the adult it is rarer still. In the 12 such cases reported in the literature,[1-11] there was a marked variation in the symptoms presented by the patient. In some, only astute questioning revealed a pertinent history.[2] In other patients, repeated respiratory infections dominated the person's existence.[3, 4, 8, 10] Other important symptoms were hemoptysis, cough productive of food, recurrent pneumonia, vomiting, and dyspnea. At times, the cough was induced by liquids but not solid food.

Radiographic studies of the esophagus using contrast media were valuable in reaching the correct diagnosis. In several instances, a gastrointestinal examination was ordered because of vomiting. The diagnosis of a tracheoesophageal fistula was a surprise finding in these cases. Radiographic study of the tracheobronchial tree was usually unrewarding. The fistula was never seen by this means if esophageal studies were normal. The bronchogram in several instances showed associated bronchiectasis.

Endoscopy was not as valuable as a gastrointestinal study with contrast media. Again, the fistula was never seen by endoscopy unless first identified by x-ray studies of the esophagus. In some cases, although the level of fistula was known, it could not be found by esophagoscopy or bronchoscopy.

The associated diseases in this small series included bronchiectasis in 3 patients[1, 9, 10]; 2 cases of mental illness—one of schizophrenia[1] and one of imbecility[4]; and 1 patient died of a carcinoma of the lung.[11] In this instance, the fistula was an incidental finding at necropsy and was situated well distant from the carcinoma. An additional patient had an associated patent ductus arteriosus and an aberrant pulmonary artery.[3]

The site of the esophageal connection to the tracheobronchial tree was reported in all patients. In 5, the communication was to the right lower lobe. Tracheal connection was noted in 4, 3 patients had openings into the left lower lobe. The fistula in the final case passed to the left main-stem bronchus.

Six cases were not treated. Three were living at the time of the report, 2 had slight symptoms,[2, 8] and 1 had moderate symptoms.[7] Three patients died with the abnormality. One woman died of asphyxia when a piece of food

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passed through the fistula and blocked the trachea.[6] One man died of pneumonia shortly after a barium swallow.[4] The third patient died of carcinoma of the lung.

Seven patients were operated upon. Three had lobectomy and resection of the fistula (authors' case and 2 others[1]). All are living and well. Two patients had pneumonectomy and excision of the tract.[3, 10] One of these succumbed to postoperative infection many months after surgery.[10] Mullard has reported another patient in whom the fistula was resected with a good result. The final patient was treated endoscopically by Clerf by silver nitrate application with a successful result.

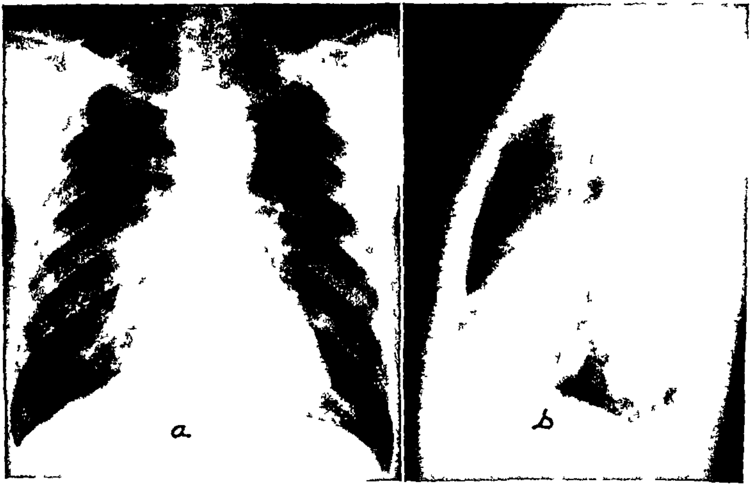

Fig. 1.—Roentgenograms made on admission. A, Front view. B, Lateral view.

CASE REPORT

W. A. O., a 39 year old white man, was admitted to the Mt. Alto Veterans Hospital on July 31, 1956, because of a 2 weeks' history of hemoptysis. The hemoptysis produced dark red to brown sputum which amounted up to one fourth of a cup daily. The patient denied a previous history of hemoptysis but stated that he had had a chronic nonproductive cough dating back to at least 1945 at which time he was hospitalized for pulmonary infection. In the past 2 years he had experienced severe coughing paroxysms on drinking hot coffee. He also recalled severe coughing spells for about the past 20 years whenever he reclined on his right side. There was no history of dyspnea, chest pain, night sweats, fever, chills, or weight loss. A history of lobar pneumonia or contact with tuberculosis was denied and the remainder of the past history was negative. The patient admitted to smoking two packs of cigarettes per day for many years.

On physical examination no significant abnormalities were noted. Blood and urine studies were normal and both sputum and gastric aspirations were negative for acid fast bacilli. X ray examination of the chest on Aug. 1, 1956, was reported as follows: Chest

TABLE I. CONGENITAL TRACHEOESOPHAGEAL FISTULA IN THE ADULT

AUTHOR	AGE	SEX	SYMPTOMS	X-RAY	ENDOSCOPY	ASSOC. ANOMALY OR DISEASE	TREATMENT	LOCATION
Abrams	38	M	Hemoptysis	Fistula seen on GI series and bronchogram	None	Schizophrenia; bronchiectasis	Lobectomy and resect fistula; alive	RLL
Berglund	62	M	Cough with cold liquids	Fistula seen on GI series, not on bronchogram	None	None	None; alive	RLL
Berman	40	F	Repeated pneumonia; hemoptysis	Fistula seen on GI series, not on bronchogram	None	Patent ductus anomalous pulmonary artery	1. Close fistula; 2. pneumonectomy and resect ductus; alive	LLL
Caldwell	54	M	Repeated pneumonia; vomiting	Fistula seen on GI series; no bronchogram	None	Imbecile	None; died of aspiration pneumonia	Trachea
Clerf	23	F	Cough on swallowing for 7 yr.	Fistula seen on GI series; no bronchogram	Fistula seen at esophagoscopy		Silver nitrate applications; alive	LLL
Krausey	38	F	Vague	None	None		None; died of aspiration	Trachea
McKinney	58	F	Vomiting; cough after meals	Fistula seen on GI series; no bronchogram	Fistula seen at bronchoscopy, not at esophagoscopy		None; alive	Trachea
Moersch (Case No. 2)	52	M	Choking and dyspnea with liquids since child; repeated pneumonia	Fistula seen on GI series; no bronchogram	Fistula seen at esophagoscopy		None; alive	LLL
Morton	26	M	Chronic cough, coughs up food; several attacks of pneumonia	Fistula not seen on bronchogram; no GI series	None	Bronchiectasis	Lobectomy; resect fistula	RLL
Mullard	54	M	Purulent sputum; coughed food; repeated pneumonia	Fistula seen on GI series and bronchogram	Fistula seen at bronchoscopy, not at esophagoscopy	Bronchiectasis	Pneumonectomy; resect fistula; late death with infection	Left main bronchus
Mullard	54	F	Vomiting	Fistula seen on GI series; no bronchogram	Fistula seen with difficulty on bronchoscopy and esophagoscopy	None	Resect fistula; alive	RLL
Negus	45	M	?	None	None	Cancer of lung	None; died of cancer	Trachea
Ware and Hall	39	M	Hemoptysis; cough with liquids	Fistula not seen on bronchogram; no GI series	Fistula not seen at bronchoscopy, no esophagoscopy		Resect fistula, lobectomy; alive	RLL

dated August 1, 1956, shows a marked prominence and increased density of the right hilum. This may be superimposition of an inflammatory process in the apex of the right lower lobe. The possibility of a neoplastic process should be considered. There are numerous blebs in the right apex. The aortic knob is prominent. The heart appears to be within normal limits" (Fig. 1). A tuberculin skin test was evaluated as 3+ while the histoplasmin skin test was negative. Bronchogram studies were reported as follows: "There is normal bronchial pattern of the right upper, middle, and all of the basilar branches of the right lower lobe. The primary branches of the apical division of the right lower lobe are also outlined. They are just above the limits of normalcy in caliber. There is no evidence of bronchial luminal obstruction or bronchiectasis." Bronchoscopic examination and right scalene node biopsy were negative. Because of the possibility of the lesion being inflammatory, it was decided to send the patient on furlough for 4 weeks and re-evaluate him after that time.

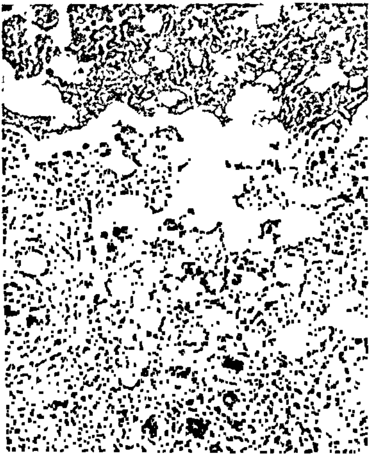

Fig. 2.

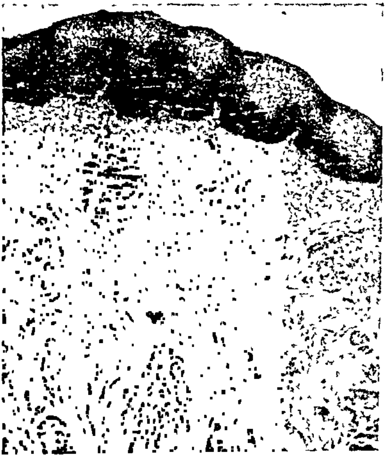

Fig. 3.

Fig. 2.—Micrograph of tissue from fistulous tract
Fig. 3.—Micrograph which shows pulmonary parenchyma.

A chest roentgenogram taken following the furlough showed no change from the admission film. On Oct. 18, 1956, a right thoracotomy was performed. There were extensive pleural adhesions, at operation, with a mass surrounded by indurated lung tissue present in the apex of the right lower lobe. It was thought that the likelihood of tumor was sufficient to warrant right lower lobe lobectomy. After dividing the arterial and venous branches to the right lower lobe, a fistulous communication was noted between the apical segment of the right lower lobe and esophagus. The tract was resected and the lobectomy completed. A Levin tube was passed into the stomach and the esophagus was closed in two layers. Postoperatively, the patient had an uneventful recovery and on follow-up examinations is asymptomatic.

Examination of the resected specimen was reported as follows: "The right lower lobe of the lung measures 14 × 8 × 7 cm. On the upper medial surface there is a tract which on opening reveals a slightly roughened lining bronchial mucosa. This extends from the pleural surface for a distance of 2 cm. and apparently communicates with the terminal bronchus. On bisecting the lobe, there are patchy firm areas throughout, some of which are reddish, while others are gray to yellow. [Microscopically] The pulmonary parenchyma is congested and the air spaces are filled with large hemosiderin-laden and vacuolated macrophages, mononuclear cells, edema fluid and debris. The alveolar walls are thickened and partly hyalinized. There are numerous areas of atelectasis, focal hemorrhage and several granulomatous lesions containing multinucleated giant cells of the foreign body type. Several bronchi form cystic branching spaces; there is a marked peribronchial fibrosis with accumulation of lymphocytes. [Fig. 2] Section from the fistulous tract shows a bronchial epithelium which in the peripheral sub-pleural area is replaced by squamous epithelial lining. [Fig. 3] Sections of the resected fistula (separate from lung) showed a fibromuscular tissue partially covered by squamous epithelium and described as compatible with an esophagobronchial communication."

SUMMARY

Congenital tracheoesophageal fistula in the adult is a rare entity. Thirteen reported cases are analyzed. Respiratory symptoms of hemoptysis, cough productive of food, and recurrent infection are predominant. Contrast examination of the esophagus is the best method of diagnosis. Bronchograms, bronchoscopy, and esophagoscopy are of limited value. Recommended treatment is resection of the fistula and, if necessary, adjoining lung tissue.

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CLINICAL STUDIES ON BRONCHOSPASM

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THE uncertain and frequently disappointing response to therapy of that wide variety of conditions which may be designated "bronchospastic" (e.g., asthma, bronchitis) seems to warrant a re-appraisal of the basic principles involved. The following study was conducted with this object in view.

GENERAL CONSIDERATIONS

Transverse section of bronchioles demonstrates that the muscular coat of those below 0.6 mm. diameter (i.e., at point of disappearance of cartilage and glands) is often incomplete or occasionally absent. The excellent monograph by W. S. Miller on the gross and microscopical anatomy of the lung shows that this is due to the geodetic arrangement of muscle fibers in the bronchiolar wall—the fibers being embedded in longitudinally disposed elastic tissue. In bronchioles of 0.6 mm. diameter, muscle bundles are found to vary from 0.02 to 0.03 mm. in thickness and 0.008 to 0.05 mm. in width.

The so-called respiratory bronchioles (diameter 0.25 mm.) branch terminally into two or three alveolar ducts, thence to atria and air sacs, but there are, in addition, alveoli protruding directly through the muscular latticework. It has recently been demonstrated (Lambert) that direct broncho-alveolar communications exist in the larger bronchi. These are seen bronchographically but are frequently misinterpreted as glands. The atria and air sacs have no smooth muscle in their walls.

The bronchioles are thus seen to be particularly well adapted to their function in respiration, namely, elongation and dilation alternating with shortening and narrowing. The muscular element, in view of its delicacy and relatively sparse distribution (cf., pulmonary veins and arteries of similar caliber), appears unlikely to have any appreciable independent activity. Further, bronchial elasticity is considerably less than that of the vessels as can be observed at segmental resection where the localization of subsegmental bronchi depends on this factor—that is, by traction and palpation.

Bronchi of greater caliber than 0.6 mm. are reinforced with wedges, plates, and hoops of cartilage to maintain patency. Patency beyond this would appear to depend largely on negative intrapleural pressure effecting distraction of bronchiolar walls via the contiguous aerating alveoli, and partly on the inherent rigidity of the fibroelastic coat.

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MATERIAL FOR STUDY

Twelve young adults, 6 male, 6 female, whose ages ranged from 22 to 27 years, were studied at the operation of segmental lung resection. Two of the females and 4 of the males gave a definite history of previous bronchospastic attacks ("asthma") in childhood and adolescence, but the clinical findings in these cases did not differ significantly from the others. Apart from strictly segmental tuberculous lesions, all the patients were in good general condition, and residual lung tissue in each case completely filled the hemithorax on moderate inflation of the lungs.

The mechanism of bronchiolar respiratory movement was studied directly at operation with a hand lens. Healthy bronchioles of 0.5 mm. diameter, as measured with a stainless steel gauge, ruptured across the intersegemental plane during stripping of the segment and others, which had been stripped along their length, showed rhythmic variation in caliber, with pressure changes in the anesthetic apparatus. The effect of temporary occlusion of the "feeder" bronchus was then observed. The subsegmental bronchus to the area in which lay the bronchioles under study was occluded with a rubber-shod clamp. Respiratory excursions persisted, although more slowly, due to air drift from adjacent unoccluded segments which filled the alveoli around the bronchioles and distracted their walls circumferentially.

On each occasion, a few of these bronchioles were removed and submitted to histologic examination. The degree of shrinkage was estimated at approximately 40 per cent. Several observers, for example, Miller and Boyd, describe a relative increase of smooth muscle at the junction of atria with respiratory bronchioles. They have even been termed ''sphincters'' in some anatomy textbooks (Gray and Cunningham). This appearance was found due to more marked shrinking and retraction of the bronchiole at the junction with the nonmuscularized atria and alveoli. Even so, the proportion of muscle ring thickness at this site to total bronchiolar lumen is 0.02 or 0.01 mm. to 0.25 mm. which implies that complete occlusion by mucular action is unlikely. There was no evidence of myohypertrophy in the "asthmatic" as compared with the normal individuals.

''HUMORAL'' EFFECTS

The direct effect of drugs on the exposed bronchioles was observed. A few minims of 50 per cent histamine were dropped on the open bronchiole; in 2 to 4 minutes the lumen diminished. It seemed that the edema affected the mucosa particularly—there was certainly no contraction of the bronchiole which was then lightly swabbed and 0.01 per cent Adrenalin applied. Again there was no detectable change in total thickness but the lumen became wider within 10 seconds.

On seven occasions following the application of histamine, papaverine was applied instead of Adrenalin. Although Parkes found this a powerful bronchial spasmolytic, no change was observed even 5 minutes afterwards. Atropine, likewise, produced no change.

NEURAL EFFECTS

Although a fairly rich supply of sympathetic and parasympathetic nerve fibers accompanies the bronchioles, that they exercise any appreciable effect upon their caliber is far from proved. Many of these fibers are vasomotor to bronchial arteries, secretomotor to glands and afferents from stretch receptors and epithelium. Only a small proportion of them is myomotor (Mitchell).

Abbott and his co-workers in their consideration of the surgical management of emphysema and intractable asthma by denervation of the lung—a full description of the operative procedure is given—claim that postoperative *bronchoscopy shows comparative relaxation of the ipsilateral bronchi* and, deductively, of the bronchioles. They are less certain, however, that this is maintained and now postulate "trigger areas" of disease, such as bronchiectasis, and that the bronchospastic attacks are due to "reactivation of an inflammatory component in a localised area of destructive pulmonary disease." More significantly, they state that "in such cases resection of the destroyed area alone may produce cure" (i.e., sputum reduction).

Klassen and his associates describe a series of 7 cases in which unilateral vagotomy was performed in inoperable bronchogenic carcinoma to allay or diminish troublesome cough. Bronchoscopic and bronchographic examination (the latter in full expiratory and inspiratory phases) showed no alteration in caliber or movement of the ipsilateral as compared with the contralateral bronchi.

Autonomic innervation of the lungs is, in part at least, bilateral (Phillips), but it seems reasonable to expect appreciable visible alteration bronchoscopically following the operative procedures, described by Klassen and Abbott, which should certainly interrupt the pathways behind the main carina as, or shortly after, they traverse the midline, if neural control is major factor.

This aspect was investigated by injection of 2 per cent Xylocaine at operation in the 8 right-sided cases, since the production of even a temporary recurrent nerve palsy was considered unjustifiable in view of its adverse effect upon expectoration.

The hilar structures were exposed routinely at operation and, following removal of the affected segments, the right vagus nerve was infiltrated with Xylocaine from the level of the first dorsal vertebra to the hilum. The stellate ganglion and dorsal ganglia of the sympathetic chain were also infiltrated as far as the level of the seventh dorsal vertebra. A ring of edema was raised in the alveolar tissue around the main bronchus, main pulmonary artery, and the upper and lower veins. Some 10 c.c. of Xylocaine were employed on each occasion.

No alteration in caliber of bronchioles on the raw intersegmental surface was observed when vagus and sympathetic nerves were blocked separately and together. Immediate postoperative bronchoscopy after thoracotomy closure (the ipsilateral pupil still showing dilation) revealed no alteration of rhythmic bronchial respiratory variation as compared with the other side of the bronchial tree. Full expansion on the side of operation was ascertained by auscultation.

DISCUSSION

Bronchospasm.—Most physiologic studies on bronchial musculature have been made on isolated bronchial chains (Hawkins and Schild) and the response of these to various drugs. The fact that such experiments ignore the powerful distraction of the bronchioles effected through contiguous alveoli by thoracic skeletal musculature would account for the consequent failure to substantiate them clinically. The experimental use of guinea pig lung which contains proportionately much more smooth muscle than human lung has further confused the issue.

Bronchoscopic examination of patients with extremely rapid respiratory rate shows bronchial rhythmicity in complete accord with thoracic and diaphragmatic excursions. In postoperative bronchoscopy of Semb-type thoracoplasty, the segmental bronchi of the upper lobe on the side of operation also exhibit "paradoxical" movement.

The relative immobility of the bronchial tree in unilateral "frozen chest" is a further example of the passive nature of the bronchial rhythm.

It seems unlikely that there is synchronous neural control of the bronchial tree during respiration. Against such reciprocal innervation of smooth and voluntary muscle is the slow rate of contraction and relaxation of which the former is capable.

The degree of ischemia and engorgement, respectively, of the lung fields during the Valsalva maneuver and inspiration against resistance (occlusion of nose and mouth) following complete expiration, can be demonstrated radiologically. The ease with which such passive alterations in the more muscular pulmonary vascular tree are induced further suggests the improbability of "spastic" bronchioles being able to maintain effective resistance.

Bronchospasm has never been reported in a patient with a dry bronchial tree. There is always increased bronchial secretion and it is unquestionable that considerable bronchiolar edema is also present. The degree of relaxation afforded in expiration, or of compression in forced expiration, will be sufficient to occlude the lumen completely.

The mechanism of bronchospasm is thus more likely to be valvular occlusion of bronchioles by edematous or thickened mucosa and/or intraluminar debris. In the few reported cases of death during asthmatic attacks (Oswald and Reid), edema and congestion of the bronchiolar wall, and particularly of *the epithelium with occlusion by mucous plugs and decidous epithelium,* were marked features at autopsy.

Muscular hypertrophy has never been demonstrated in such cases and this tissue in common with the other constituents of the bronchiolar wall merely shows edema.

In allergic asthma, this concept would seem to be supported by the fact that other allergic manifestations such as rhinitis, conjunctivitis, urticaria, among others, produce maximal effect upon epithelial surfaces. The inhalation of irritating particles of dust, pollen, or gases such as tear gas or chlorine, produces a marked increase in bronchial secretion with congestion of the respiratory epithelium. Whether the edema and congestion is due to direct irritation or to a topical antigen antibody response, as in allergic asthma, is presently irrelevant, it seems probable that the result is identical in each instance and that muscle spasm plays no part in it.

The typical "bronchospastic" attack responds, although by no means invariably, to Adrenalin ("adrenalin resistance" as described by Carr), when administered as an aerosol spray or by subcutaneous injection, and the former method of administration is as, if not more, effective than the latter. The action is probably a vasomotor one on the bronchial mucosa. The tardier beneficial effect of atropine due to inhibition of bronchial secretion has widespread application in the postoperative management of thoracic surgical patients with troublesome copious watery sputum, but there is no experimental or clinical evidence of marked bronchodilator activity—in fact this drug has been shown to have a bronchoconstrictor action (Burstein and Parrott).

Bronchiectasis.—Bronchographic study in asthmatics is notoriously difficult but Overholt and co-workers in a series of 76 cases of asthma (the bronchitis emphysema syndrome), found bronchiectasis in 27, of which 13 cases were bilateral. All of them warranted resection.

As the myelastic coat of the bronchial tree seems designed primarily for the maintenance of "tone" during respiration, destruction or weakening by an infective process—either pyogenic or even tuberculous—of the bronchial walls will inevitably lead to dilation, i.e., bronchiectasis.

Three main factors are held to be concerned in the production of saccular or cylindrical bronchial dilation (Cappel).

1. Atelectasis of associated parenchyma with resultant increased negative pressure on the bronchial walls.
2. Weakening and excavation of the bronchial walls due to infection.
3. Contraction of peribronchial fibrosis.

Whether or not the surrounding parenchyma is atelectatic, consolidated, more or less normally aerated, or even emphysematous, will affect only the rate of onset of bronchiectasis for, in each instance, the bronchi are relatively wide (or in atelectatic or consolidated lungs—the only) air filled spaces with distensible walls. Thus, in the atelectatic lung, the full distractive force is acting upon the bronchial walls alone. Since long continued pressure changes can only be withstood by muscle tissue (cf. ligaments of joints in paralyzed limbs) when this is destroyed gradual stretching of the elastica and supervening fibrous tissue results.

Histologically, the most striking feature in bronchiectasis is the destruction of the muscular and elastic tissue of the bronchial walls with dilation, infective hyperplasia and ulceration of the bronchial epithelium. In many instances, the resected lobe or segment may show no diminution in volume and the parenchyma both macroscopically and even microscopically appears normal. Indeed, it is sometimes a matter of some difficulty at operation to decide whether or not the appearance at thoracotomy justifies resection at all, although at the hilar dissection in such instances the extremely thin, friable state of the affected bronchi often leaves little doubt.

In a somewhat smaller number of cases, the bronchographic appearances may return to normal following conservative therapy (breathing exercises and postural coughing). In these cases of reversible bronchiectasis (D'Abreu), it would seem that the muscle has either not been severely damaged or has recovered sufficiently to exercise adequate tonal control. There are grounds for considering the possibility of smooth muscle regeneration following control of the destructive process (Maximow and Bloom), although it is doubtful if the subsequent architectural distortion would allow of complete reversal to normal.

CONCLUSION

The effect of bronchiolar muscle spasm is negligible in view of the relatively sparse distribution of this tissue. The skeletal musculature of the thoracic cage is responsible for variation in caliber. The function of the musculature of the bronchial tree is maintenance of tone. When this is lost due to damage or destruction of the myelastica, bronchiectasis occurs.

Were it possible for the so-called sphincters at the bronchiolo-atrial junction to effect closure, the sequence would be rapid absorption of alveolar air, namely, atelectasis; the alveoli, however, in severe asthma are maximally distended and emphysematous.

Present trends in therapy of so-called bronchospastic conditions suggest that undue attention has been directed toward relaxation of the bronchial musculature for, although many excellent spasmolytics are available, their effect thereon is at best variable. Antibiotics to allay infection, bronchial "detergents" incorporating trypsin and hyalase which reduce secretion viscosity and liquefy fibrinous exudates, antibody-antigen block by desensitization, and antihistamines to minimize the local edema of the allergic response are considerably more effective, although the last named are probably less so than the others.

SUMMARY

The humoral and neural influences upon bronchiolar caliber have been studied in relation to the histoanatomical structure, both directly at operation and indirectly at bronchoscopy. It is suggested that the only important factor is alteration in pleural pressure and that the mechanism of clinical bronchospasm bears little relation to intrinsic bronchial musculature, but is entirely due to edema or mechanical block of the lumina. It is further suggested that the main etiological factor in the production of bronchiectasis is loss of or damage to bronchial musculature.

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THE BRONCHUS STUMP

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Long after the general adoption of the Listerian principles in surgery had lessened the role of infection in operations elsewhere, postoperative infection remained a serious deterrent to chest surgery. Controlled, positive-pressure endotracheal anesthesia removed the fear of the consequences of the open chest. The appreciation of the importance of individual hilar dissection and the more liberal use of blood transfusions removed the fear of uncontrolled hemorrhage and operative shock. But, regardless of how the bronchus was closed, it practically always reopened in the postoperative period with the development of an empyema and a bronchopleural fistula. Thus, it was that in 1935 a mortality rate of 64 per cent in lobectomy for bronchiectasis was considered encouraging. The majority of the deaths and complications were the result of breakdown of the bronchus stump. Even today the commonest cause of failure in the surgery of lung resection, especially in pulmonary tuberculosis, is bronchopleural fistula (Table I). Because of this the author felt that it would be valuable to re-emphasize some of the principles of bronchus closure.

TABLE I. THE BRONCHOPLEURAL FISTULA RATE IN PULMONARY RESECTION FOR TUBERCULOSIS COLLECTED FROM PUBLICATIONS BETWEEN 1951-1958 FROM CANADA, UNITED STATES, GREAT BRITAIN, AND FRANCE

NUMBER OF RESECTIONS	NUMBER OF BRONCHOPLEURAL FISTULAS	PER CENT B-P FISTULAS
7,750	520	6.7

CAUSES OF BRONCHUS BREAKDOWN

Infection.—Without a doubt, infection of the sutured bronchus stump is the commonest cause of its failure to heal. The possible sources of infection are extrabronchial, endobronchial, and intrabronchial.

First, extrabronchial infection may arise from accidental contamination of the pleural space from spillage of secretions during resection, from rupture into cavities, abscesses or solid (usually tuberculous) lesions during mobilization of the lung, and from breakage into or incision of infected hilar lymph nodes during dissection of the bronchus stump. Peribronchial infection, too,

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may result from transgression of infected tissue planes, particularly in segmental resection for pulmonary tuberculosis. Infection may also occur outside of the stump as a result of leakage of intrabronchial secretions if closure of the bronchus stump has been inadequate. A further source of extrabronchial infection is failure to eliminate rapidly the pleural dead space following resection of a segment or lobe. The results of such infection are peribronchial abscesses, with or without an overt thoracic empyema, and stump breakdown.

Second, endobronchial infection is usually a complication of the surgical resection of tuberculous lung. It has been clearly shown that tuberculous involvement of the mucosa and submucosa, at the line of section, is present in more than two thirds of resected bronchi. It depends on the degree and activity of this tuberculous process how serious a deterrent such involvement is to wound healing. Endobronchial infection is of lesser importance in the surgery of bronchiectasis or other pulmonary infections.

Third, intrabronchial infection is almost entirely a complication of poor surgical technique by which a long bronchial stump is left as a cul-de-sac for the collection and infection of retained bronchial secretions.

By any of the above modes of infection, delayed healing or actual disruption of the bronchus stump may occur since infected structures rarely heal well. A thoracic empyema may precede or follow the breakdown of the bronchus so that bronchopleural fistula and empyema are usually concomitant complications.

Devitalization.—Close to infection is devitalization of the cut end of the bronchus as a cause of stump breakdown. The bronchus heals at its end and if this end is deprived of an adequate blood supply then necrosis is inevitable.

Coverage.—Failure to cover the bronchial suture line with living intrathoracic tissue is probably one of the gravest errors in bronchus suture. The classic experiments of Rienhoff and co-workers[3] have shown that a pleural flap alone, without bronchus suture, will prevent fistula formation in the experimental animal.

Technique.—Errors in technique rank high among the causes of bronchopleural fistula. Although these will be discussed in detail later, the more important errors are too long a stump, devitalization of the stump, too much suture material, and inadequate coverage of the suture line.

PREVENTION OF BRONCHUS BREAKDOWN

With the knowledge that most bronchopleural fistulas result from infection, devitalization of the stump, or technical error, some observations can be made on their prevention.

First, no patient should be operated upo [illegible] which he is suffering is adequately controlled. Thi [illegible] n pulmonary tuberculosis where endobronchial disease is such a major source of fistula formation. Months of preoperative antimicrobial therapy may be necessary before the "target point" is reached. In bronchiectasis and pulmonary abscess, preoperative physiotherapy and the appropriate antibiotics must be administered until the bronchial tree is as "dry" and infection free as possible. These measures will ensure a healthy bronchus stump and a minimum of secretions in case of accidental spillage during resection. These points are of lesser importance in the surgery of pulmonary cancer except when the lung distal to the growth is infected.

Second, when lung overlying cavities, abscesses, or solid caseous lesions is being mobilized it must be done extrapleurally so that the lesion is not broken into and the pleural space contaminated. Except in pulmonary cancer, overzealous gland dissection must be avoided lest caseous and/or infected nodes be broken into with resulting peribronchial infection.

Third, transgression of infected tissue planes must be avoided by substituting a lobectomy for a segmental resection if the latter procedure is going to mean stripping through infected lung. This problem is almost exclusive to segmental resection in pulmonary tuberculosis.

Fourth, rapid elimination of the pleural dead space after resection is important in reducing postoperative empyema and fistula. This is obtained by careful preoperative physiotherapy and sustained postoperative physiotherapy to aid rapid elimination of the dead space. Adequate tube drainage of the pleural space with or without suction will encourage expansion of the lung. Finally if there is obviously going to be considerable discrepancy between the remaining lung and the pleural space, space reduction by phrenic crush, pneumoperitoneum, or thoracoplasty must be done.

Fifth, the most important source of breakdown of the bronchus stump is failure to observe high division of the bronchus. If the bronchus is not divided almost flush with the trachea during pneumonectomy or as close to the parent bronchus as possible during segmental resection or lobectomy, then a sump for the accumulation of secretions is left. This is the greatest source of postoperative stump infection, delayed healing, and breakdown.

Sixth, devascularization and sloughing of the stump can be limited by avoiding overzealous peribronchial gland dissection except in pulmonary cancer. Extensive peribronchial dissection will unavoidably damage bronchial arteries and lead to devitalization of the termination of the bronchus. When a bronchial artery must be controlled, a terminal transfixion stitch of fine silk is used just proximal to the level of bronchus section. Also proximal clamps are best avoided unless they are of the noncrushing type, e.g., Pott's artery clamps.

Seventh, no resection is complete unless the suture line is covered, preferably by living intrathoracic tissues. The best and simplest tissue is a pedicled pleural flap but a free pleural graft, mediastinal tissues, pericardial flaps, and even pedicled intercostal muscle bundles may be used. It has been shown that this step is more important than any other except flush resection of the bronchus stump. The animal experiments of Rienhoff[3] demonstrated this point beautifully.

Eighth, although many authors place great reliance on a particular type of suture material, the amount of suture material and the carefulness of its placement are probably as important as the type of material. It is generally agreed that nonabsorbable suture material is best, although Björk[1] recently claims equally good results with catgut. Most authors favor fine atraumatic silk or atraumatic stainless steel wire and the fewest sutures compatible with closure should be used. These must be tied firmly enough to ensure an air-tight closure but not so tight as to cause necrosis or to cut through—approximation without strangulation.

Finally, the technique of closure itself may be the cause of bronchopleural fistula. Most of the possible errors in technique have been mentioned above but these will be re-emphasized as I describe the simple technique of bronchus closure I have used in over 200 consecutive resections.

TECHNIQUE OF BRONCHUS SUTURE

Recognizing the points already discussed, the technique of closure of the resected bronchus rests upon several very important principles. These could be summarized in the following adjectives—gentleness, brevity, simplicity, and coverage. Since resection of the right upper lobe is one of the commonest resections in pulmonary tuberculosis and one of the commonest sources of fistula let us consider the surgical technique of dealing with this bronchus as our example. Let us assume that all the essential steps prior to the actual bronchus section have been performed.

Minimal peribronchial dissection is done with no stripping of tissues and no overzealous gland dissection except in cancer surgery. Thus, the bronchial blood supply is not compromised. The bronchial arteries, usually three in number, are underrun with 3-0 atraumatic silk and tied as close to the parent bronchus as possible, since this will be immediately proximal to the line of section. This ensures an adequate blood supply to the cut end of the bronchus and also prevents these sometimes formidable vessels from spurting during the closure of the bronchus—an important point if the open-bronchus technique is being used. A Brock (toothed) bronchus clamp is placed as distal as possible on the bronchus and closed completely. This prevents spill from the lung when the bronchus is cut and I have never known this clamp to come off. Then a curved Pott's aorta clamp is placed across the right upper lobe bronchus, flush with th
and the
ture can
ons with
no complication. Its presence prevents escape of anesthetic gases and spillage of secretions, blood, or other elements into the bronchus. It also relieves one of any hurry in suturing the bronchus which can be sutured, in full view, carefully and unhurriedly after the lobe (lung or segment) has been removed.

Nonabsorbable suture material is used
or No. 36
stainless steel wire on
or wire is
used, two 2-0 silk stay

of the bronchus. The Pott's clamp is removed and the bronchus is closed by the open technique. A through-and-through stitch is placed centrally and two additional stitches are placed on each side of this central one. The two stay sutures are tied and the ends left long. Seldom are more stitches needed to ensure adequate closure. The bronchus stump is covered by 1/1000 proflavine solution while the anesthetist applies 25 to 30 mm. Hg pressure to the suture line by squeezing on the bag to test the airtightness of the closure. As few stitches as possible are used. Two for a segment and five to seven for a lobe or lung are usual. There is no need for complex closures, curvilinear incisions, dissection or cutting of cartilages, or mattress stitches. Brevity of stump length and brevity of suture material is combined with a simple stitch to ensure firm apposition without strangulation.

A large pedicled pleural flap is then raised from the posterior chest wall and sewn down onto the suture line by means of the two stay sutures which are rethreaded. If silk has been used throughout, additional stitches are left long and rethreaded so that the pleural flap can be closely approximated to the suture line and not just "tented" over it. "Tenting" leads to the accumulation of blood around the suture line with the danger of a peribronchial hematoma forming and leading to a peribronchial abscess. Careful reinforcement of the suture line is next to high division of the bronchus in preventing fistula. The two points are complementary because a short stump (as well as being more easily covered) retracts into the mediastinum and so buries itself. Surrounding mediastinal tissues, pericardial fat, or flaps, free pleural grafts, and hinged intercostal muscle bundles can also be used but pleura is simple and adequate and generally available. Even a free pleural graft adds greatly to the tensile strength of the bronchus closure.[2]

The pleural space is washed out with proflavine and, after this is sucked out, 1 gram of streptomycin crystals and 50,000 units of bacitracin powder are placed over the site of the bronchus stump. The chest is closed leaving one apicobasal No. 40 Bardex whistle-tip catheter in the chest for the removal of air and blood during the postoperative period. This is connected to 3-bottle suction at 20 mm. Hg suction pressure.

Using the above technique, over 200 consecutive resections have been performed with only 2 bronchopleural fistulas. These 2 fistulas developed in 150 resections for pulmonary tuberculosis. Both bronchi (a right upper lobectomy and a left apicoposterior segmental resection) were closed with silk. No fistulas have occurred when wire was used to close the stump and there have been no fistulas after resection for bronchogenic carcinoma or bronchiectasis, or after segmental resection for simple pulmonary tumors or other lesions. Wire imparts no greater tensile strength to the bronchus closure[2] but, by its inertness and its nature, which requires greater care in its use, wire is the preferable nonabsorbable suture for bronchus closure. This is particularly so in tuberculosis where there is a high (histologic) incidence of endobronchitis at the suture line and in bronchogenic carcinoma where an extensive hilar gland dissection usually accompanies the resection.

SUMMARY AND CONCLUSIONS

Problems associated with the closure of the bronchus stump have been reviewed. Infection, devitalization, and errors in technique are the commonest causes of bronchus breakdown. These can be avoided by observing "flush" section of the bronchus to avoid a sump, by gentleness in peribronchial dissection to avoid devascularization of the stump, and by the use of as few sutures as possible to close the stump which must be carefully covered by living intrathoracic tissues. Wire is the preferable suture material for bronchus suture. An incidence of less than 1 per cent bronchopleural fistula is recorded by observing these principles in over 200 pulmonary resections.

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PRIMARY REPAIR OF FRACTURE OF THE LEFT MAIN-STEM BRONCHUS

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FRACTURE of a main-stem bronchus is said to be a relatively common complication of severe trauma to the thorax. However, the opportunity to treat such an injury of the left main-stem bronchus is relatively rare since the patient does not usually survive because of laceration of the closely related aorta.

The condition was described in 1906 by Barford,[1] in England, at autopsy following severe chest trauma. Sanger,[2] in 1945, reported 2 cases in which successful suturing of the bronchus was carried out, but it was not until 1948 that Griffith[3] reported the first successful resection of a stricture and re-establishment of continuity 8 months following injury. The longest interval between injury and repair was 15 years. Mahaffey[4] reported a case successfully repaired 11 years following injury. The ventilatory function improved progressively in this case; however, oxygen consumption did not improve equally and the patient was partially desaturated following breathing 100 per cent oxygen.

CASE REPORT

A 22-year-old airman was admitted to the 7100th USAF Hospital on Oct. 10, 1956, following an automobile accident 24 hours previously. He was driving and had struck his chest against the steering wheel after hitting a tree.

On admission he was lethargic and breathing heavily. There was subcutaneous emphysema over the left chest with the cardiac border shifted to the right. Hamman's sign was present. There were no localizing neurological signs. Blood pressure was 108/70 mm. Hg; pulse, 96, and respirations, 28. There were decreased breath sounds over the left chest and swelling of the right supraclavicular area. Abrasions over the forehead were present.

On admission, the hematocrit was 43 per cent; the white cell count and differential were normal; urinalysis was negative. Roentgenograms revealed 60 per cent pneumothorax on the left side with severe mediastinal and subcutaneous emphysema (Fig. 1).

On the day of admission a multiperforated No. 28 colon tube was inserted into the left chest laterally and threaded up to the apex of the chest. There was egress of air and fluid revealing a tension pneumothorax. On the following day, the lung was expanded (Fig. 2). On October 12, the patient was cyanotic and dyspneic, with a fever of 102° F. An electrocardiogram was negative. Roentgenograms revealed complete atelectasis of the left lung, with marked shift of the mediastinum to the left (Fig. 3). Minimal pleural reaction was present. Bronchoscopy revealed a necrotic area completely stenosing the left main-stem bronchus, 3 to 4 cm. from the carina tracheae. The bronchoscope could not be passed beyond this area and blind

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probing did not seem advisable because of the possibility of perforation into the mediastinum. A tracheostomy was performed. On October 16, bronchoscopy yielded identical findings. During this time the left lower lobe was completely atelectatic and pneumonitis developed in the right lower lobe. The patient was cyanotic even in an oxygen tent. He was treated with antibiotics and began to improve clinically as the pneumonia in the right lower lobe resolved (Fig. 4). On October 17, a planigram showed an obstructed left bronchus with a small amount of air in the bronchi beyond (Fig. 5). A bronchogram on October 19 demonstrated a 2 cm. segment of obstruction which permitted a very small amount of Dionosil to pass along the inferior border of the bronchus; this was interpreted as a fracture with granulation tissue (Fig. 6). Pleural reaction increased rapidly after October 16, to produce a massive effusion with shift of the mediastinum to the right which required repeated thoracentesis from the sixteenth to the thirtieth of October (Fig. 7).

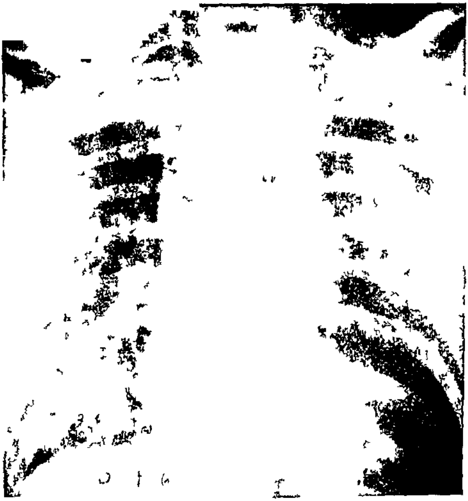

Fig. 1.—Oct. 10, 1956. The initial film demonstrates left pneumothorax, mediastinal and subcutaneous emphysema of marked degree. There is no mediastinal shift.

It was thought that if drainage of the left lung could not be established soon pulmonary function and even the lung itself would be lost due to bronchiectasis or lung abcess; further, that the fractured superior border of the left main bronchus would continue as the source of mediastinitis and effusion. On Nov. 1, 1956, a left thoracotomy was performed. The left lung was collapsed and approximately 3 L. of fluid were present. The dissection at the left hilum was difficult because of the previous mediastinitis. After the arch of the aorta had been partially mobilized, the left main stem bronchus was visualized and revealed a complete fracture of the bronchus which included the mucous membrane. The surrounding mediastinal structures had fallen into the fracture line causing occlusion of the bronchus. The bronchus was opened and the excess mediastinal tissue was cut away. Thick mucoid material was aspirated from the bronchus. The bronchus was closed, using one layer of interrupted No. 3-0 silk. The bronchus was not as firm on the cartilaginous side as the operator wished due to softening of two cartilaginous rings. The endotracheal catheter, which had previously been *down the right main stem bronchus during the operation to isolate the left side*, was moved back into the trachea and the left lung expanded and deflated well.

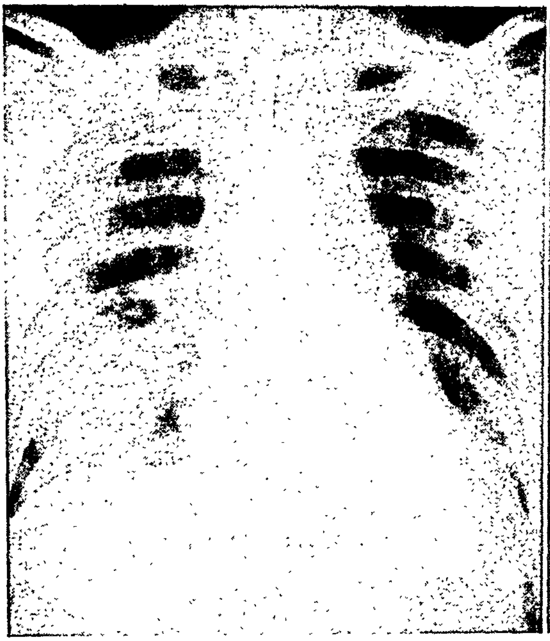

Fig. 2.

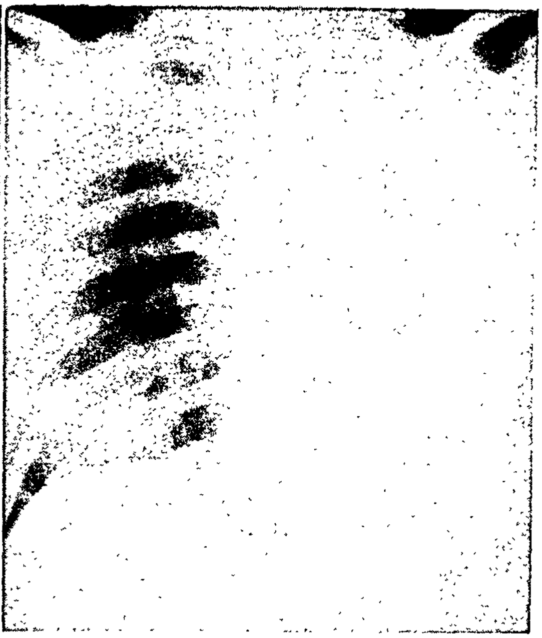

Fig. 3.

Fig. 2..—Oct. 12, 1956. Left intrathoracic tubes were removed after full re-expansion of the left lung and progressive resolution of mediastinal and subcutaneous emphysema. A *pneumonic infiltration* is conspicuous at the right base.

Fig. 3.—Oct. 13, 1956. There is opacification of the left hemithorax due to a large effusion and atelectasis. In spite of effusion the atelectasis resulted in mediastinal shift to the left. Pneumonia at right base again noted.

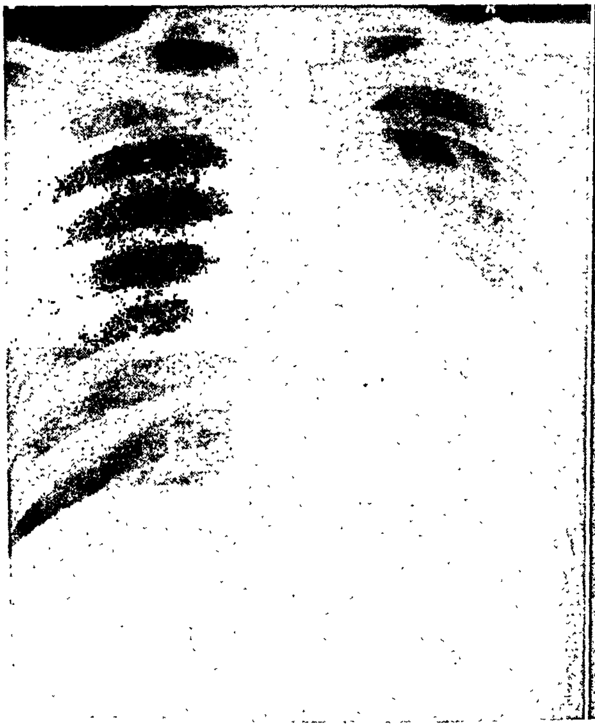

Fig. 4.

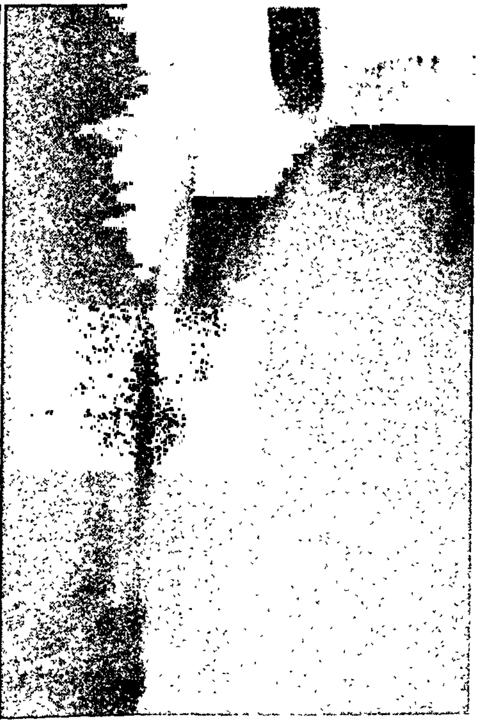

Fig. 5.

Fig. 4.—Oct. 17, 1956. The mediastinal shift persists in spite of repeated bronchoscopy and thoracentesis. Right bronchopneumonia cleared.

Fig. 5.—Oct. 17, 1956. Planigram demonstrates obstruction 2 cm. beyond the origin of left main-stem bronchus.

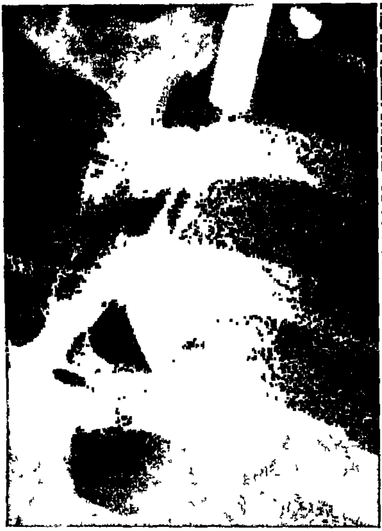

Fig 6

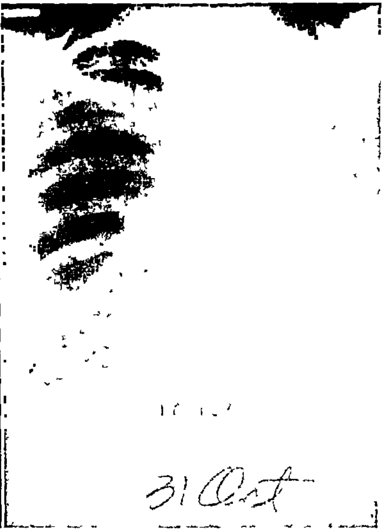

Fig. 7.

Fig 6—Oct 19, 1956 Oily Dionosil, instilled without anesthesia, demonstrates an abrupt impingement on the upper aspect of the left main-stem bronchus for about 1.5 cm A thin passage along the inferior border is open, but the lobar bronchi beyond could not be filled

Fig 7—Oct 31, 1956 Recurrent massive left pleural effusions have returned the mediastinal structures to the midline in spite of atelectasis.

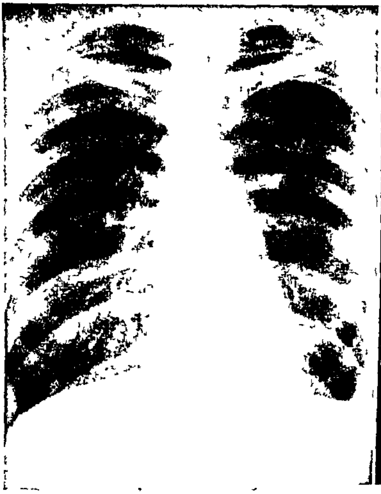

Fig 8

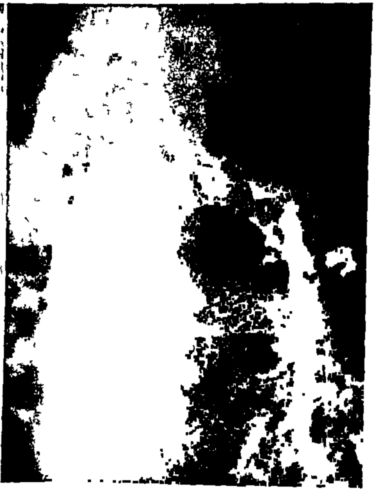

Fig 9.

Fig 8—Oct 8, 1957 The chest is essentially normal except rating left fifth rib and minimal pleural reaction at the

Fig 9—Oct 9, 1957. Bronchogram bronchus. The narrowing occurs where two

During the next 2 months periodic bronchoscopy was performed to make certain no stricture was forming. The patient's last visit was one year following surgery (Fig. 8) at which time a bronchoscope easily passed the area of anastomosis; however, a bronchogram (Fig. 9) showed indentation on the upper border of the bronchus at the cartilage defect, but without a stricture, as observed at bronchoscopy. Although no preoperative function studies were carried out, one year following surgery the vital capacity was 95 per cent of normal and the maximum breathing capacity was 101 per cent of normal. At the present time he is doing full duty as an aircraft crew chief.

SUMMARY

This case represents a fracture of the main-stem bronchus due to a crushing injury of the chest with a force of injury being transmitted to a closed hollow viscus. It is unusual that the patient experienced no broken ribs or hemoptysis; however, similar cases have been reported.[4] The immediate expansion of the left lung by closed-tube drainage, followed by complete atelectasis the next day can be explained by the entrance of adjacent mediastinal tissue into the fracture site, causing complete stenosis. Planigraphy and bronchography supplemented bronchoscopy to demonstrate the site and length of injury. Repair was performed 20 days following injury. It is suggested that the treatment of fracture of a main-stem bronchus is re-establishment of continuity as soon as clinically possible, so as to prevent bronchiectasis or abscess with the resultant loss of pulmonary functions.

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THE TREATMENT OF APPARENT SOLITARY PULMONARY METASTASES

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In caring for patients with malignant neoplasms, evidence of a distant metastasis ordinarily is considered synonymous with uncontrollable disease In the past few years, there have been several reports of gratifying results following treatment of apparent solitary pulmonary metastases.[1-6] Treatment in these reported cases has been surgical This is a report of 7 cases in which treatment of apparent solitary pulmonary metastases may have been of value in the care of patients In one of these, the only treatment of the pulmonary metastatic lesion was by irradiation, while in a second, renewed local progression of the metastatic lesion, following initial response to irradiation, necessitated resection. The other 5 patients were treated initially by resection.

CASE REPORTS

Case 1—The patient was a 53 year old white woman who had had her left forearm amputated 12½ years previously for malignant synovioma involving the wrist One and one half years later, a mass was noted in the lower lobe of the right lung (Fig. 1). A right pneumonectomy was performed at that time The tumor measured 10 by 6 by 5 cm. and was moderately well encapsulated The pathologic diagnosis was malignant neoplasm consistent with metastasis from the malignant synovioma of the left wrist This patient remains well 11 years after resection of the pulmonary metastasis

Case 2.—This patient was a 60 year old white woman who had been seen at the Tumor Institute 11½ years previously because of abnormal vaginal bleeding of one month's duration. The cervix was firm and nodular. There was palpable induration and ulceration extending into the left vaginal vault. The pathologic report was adenocarcinoma of the endocervix Treatment was by means of vaginal and intrauterine radium, followed by 800 kv. roentgen therapy to the pelvis Nine and one half years ago, a 1 cm. diameter nodule was noted in the upper lobe of the right lung (Fig 2) Because this patient was employed in a tuberculosis hospital and there was apparent central calcification in the nodule, observation was recommended. Following x ray evidence of increase in the size of the nodule (Fig 3), the upper lobe of the right lung was resected 6 years ago The pathologic diagnosis of the lung nodule was metastatic adenocarcinoma This patient is well 6 years after resection of the metastatic lesion and 11½ years after treatment of the primary lesion of the endocervix.

Case 3—The patient was a 43 year old white man who had had an enlarging pigmented lesion of the skin of his left back treated elsewhere by electrocautery 9 years previously. One and one half years later, a nodule was excised from the left anterior axillary line. This was reported elsewhere as "malignant tissue." This patient was first seen at the Tumor

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From the Tumor Institute of The Swedish Hospital
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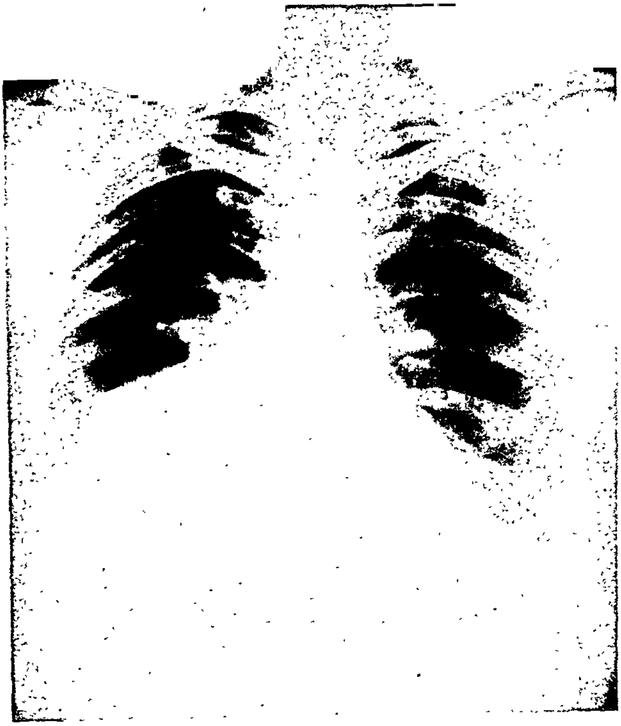

Fig. 1.—Case 1. Metastatic synovioma in the lower lobe of the right lung noted 18 months after resection of malignant synovioma of the left wrist.

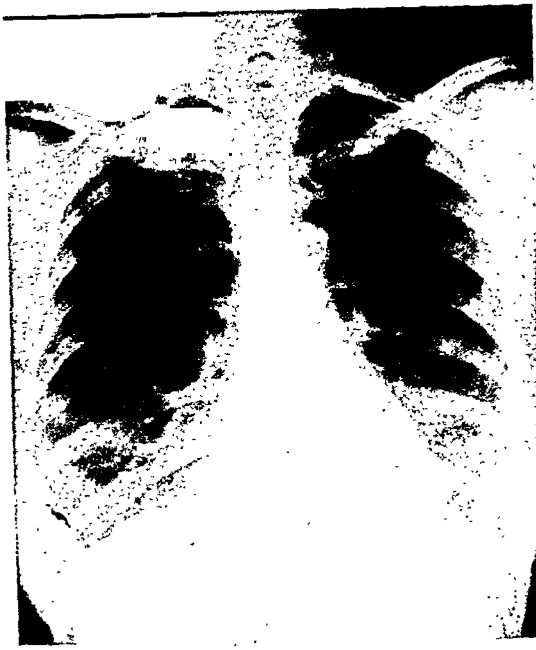

Fig. 2.

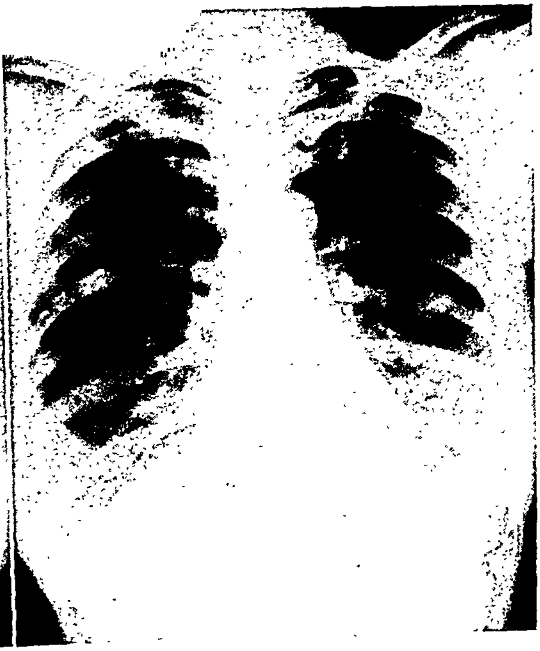

Fig. 3.

Fig. 2.—Case 2. Pulmonary parenchymal nodule noted 9½ years ago, 2 years after treatment of adenocarcinoma of endocervix.

Fig. 3.—Case 2.—Lesion shown in Fig. 2, 3½ years later, when upper lobe of right lung was resected 6 years ago.

Institute 7 years ago. At that time, because of palpable abnormality beneath the scar of the previous excision in the anterior axillary line and in the left axilla, a wide excision, with removal of the pectoralis muscles, and a left axillary dissection were performed. There was metastatic malignant melanoma in the palpable mass and in one of fourteen axillary nodes examined. Two months later, three posterior left chest wall skin nodules were removed. Five years ago, this patient reported to The Swedish Hospital with severe hemoptysis. On chest x-ray, there was evidence of a left hilar mass (Fig. 4). Because of the onset of massive hemorrhage, the exact site of origin of the bleeding could not be determined at bronchoscopy. A left pneumonectomy was performed in an attempt to control this massive hemoptysis. There was a firm mass within the lung, immediately distal to the left hilus. On examination, this ovoid tumor, 3 by 2½ by 2½ cm., had eroded bronchial cartilages and was projecting into a major bronchus in the anterior lower lobe. The pathologic diagnosis was metastatic malignant melanoma. There was no histologic evidence of metastatic tumor in thirteen lymph nodes examined. A local recurrence in the scar on his back was excised 1 year ago and, to date, 5 years after pneumonectomy, this patient remains clinically well.

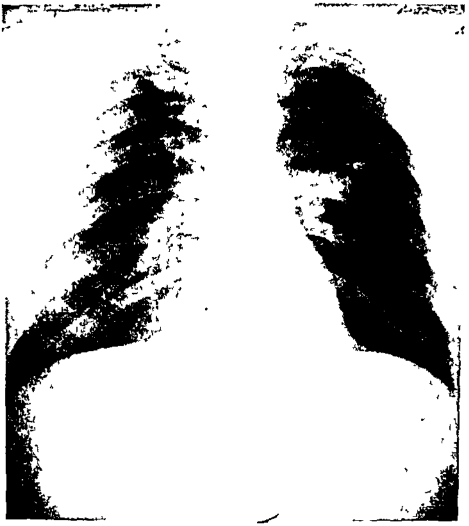

Fig 4.—Case 3. Metastatic malignant melanoma eroding cartilages of proximal major bronchus of lower lobe of left lung

Case 4.—This patient was a 44 year-old white woman who dated a mass in her right breast from the onset of menses 35 years previously. A second mass in the same breast had been present for the preceding 12 years. The larger mass, first noted in the breast, recently had increased in size prior to her initial examination at The Swedish Hospital. Following a biopsy report of fibrosarcoma from the larger mass, a right simple mastectomy had been performed 6 years previously. The pathologic report of the smaller mass was fibroadenoma. The patient then was followed elsewhere by a physician for whom she worked, until 2 years ago, when she returned with a 6 week history of severe nonproductive cough. At that time, there was x-ray evidence of a mass in the upper lobe of the left lung (Fig. 5). The upper lobe was then resected and it was noted that this 5 by 4 by 2 cm., well-circumscribed tumor extended to the pleural surface. The pathologic diagnosis was metastatic sarcoma

The patient was clinically well until 6 months later, when she complained of severe left headache. One month later, she was hospitalized elsewhere for this complaint and craniotomy was performed for a tumor in the left cerebral hemisphere which proved to be metastatic. The patient died postoperatively.

CASE 5.—The patient was a 39-year-old white man who had had a left orchiectomy 5 years previously. The pathologic diagnosis was embryonal carcinoma with blood vessel invasion. He was then seen at the Tumor Institute where postoperative 400 kv. roentgen therapy was directed to iliac and periaortic lymphatic pathways to the level of the renal pedicles. The calculated midplane dose was 3,000 r in 47 days. One year later, two nodules, with greatest dimension of 4 cm., were noted in the superior dorsal segment of the lower lobe and lingula of the left lung (Fig. 6). These nodules were treated with 400 kv. x-ray through opposing anterior and posterior fields, 10 by 10 cm. The calculated midplane dose in the chest was 2,300 r in 20 days. As can be seen on the accompanying x-ray reproduction (Fig. 7), 6 months later the residual lesion in the lung was barely evident. Fourteen months after roentgen therapy, one nodule had regrown to an estimated diameter of 3 cm. (Fig. 8). At that time, the lower lobe of the left lung was resected. The pathologic diagnosis was metastatic embryonal carcinoma. This patient remains well 30 months after pulmonary resection.

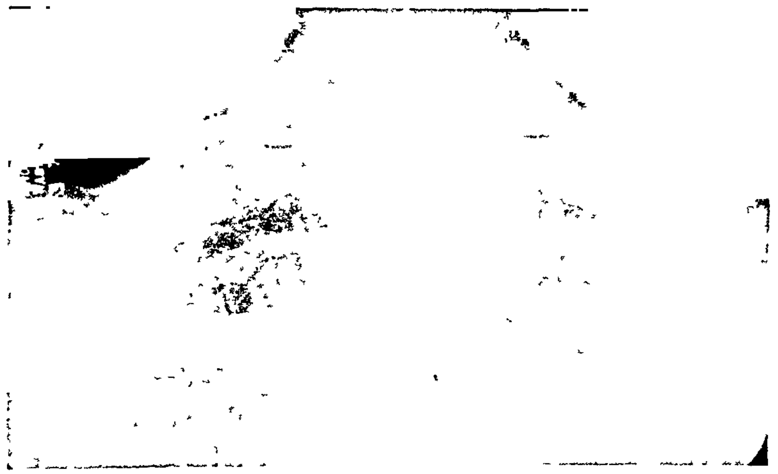

Fig. 5.—Case 4. Metastatic sarcoma in the upper lobe of left lung 4 years after right simple mastectomy.

CASE 6.—The patient was a 26-year-old white man who had had a right orchiectomy 3½ years previously. The pathologic diagnosis was malignant teratoma with embryonal carcinoma. He was seen at the Tumor Institute postoperatively, where 400 kv. roentgen therapy was directed to the right iliac and periaortic lymphatic pathways to the level of the renal pedicles. The calculated midplane dosage was 2,500 r in 43 days. Six months later, there were at least two nodules, with greatest dimension of 3 cm., in the right midlung as visualized on x-ray studies (Fig. 9). The involved portion of the lung was treated with 2 MEV roentgen therapy through opposing anterior and posterior circular fields, 8 cm. in diameter, with a calculated mid-plane dose of 3,000 r in 29 days. The lesion visibly disappeared on x-ray within 6 months. Three years later, the lungs appear normal in x-ray studies of the chest (Fig. 10). It should be noted that in this case, as in the other in which roentgen therapy was directed to the lung, there is no x-ray evidence of pulmonary parenchymal damage.

CASE 7.—This patient was a 57-year-old white man who was first seen in the Tumor Institute 2½ years ago. He had had a right orchiectomy 9 years before. The pathologic diagnosis at that time was interstitial cell hyperplasia of the testis with a question of

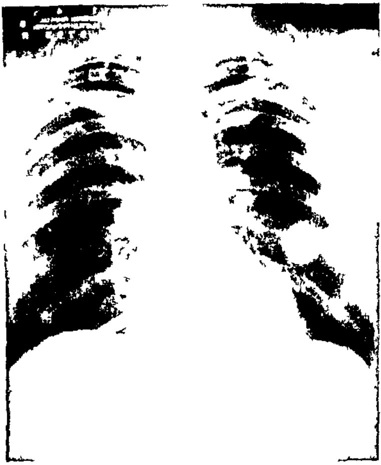

Fig 6

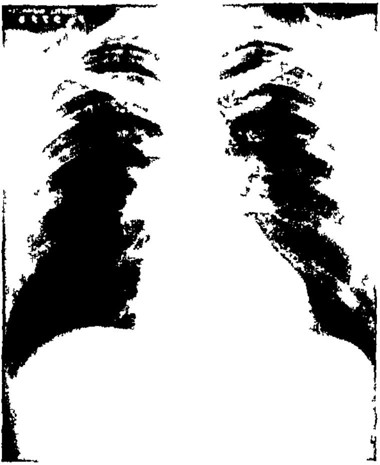

Fig 7

Fig 6 —Case 5 Metastatic embryonal carcinoma in lingula and lower lobe of left lung 1 year after orchiectomy and postoperative irradiation

Fig 7 —Case 5 Minimal residual abnormality 6 months after roentgen therapy to pulmonary metastases

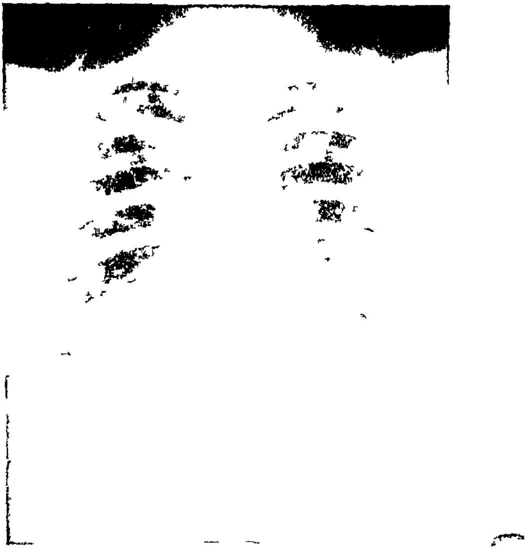

Fig 8 —Case 5 Regrowth of pulmonary metastatic embryonal carcinoma 11 local roentgen therapy

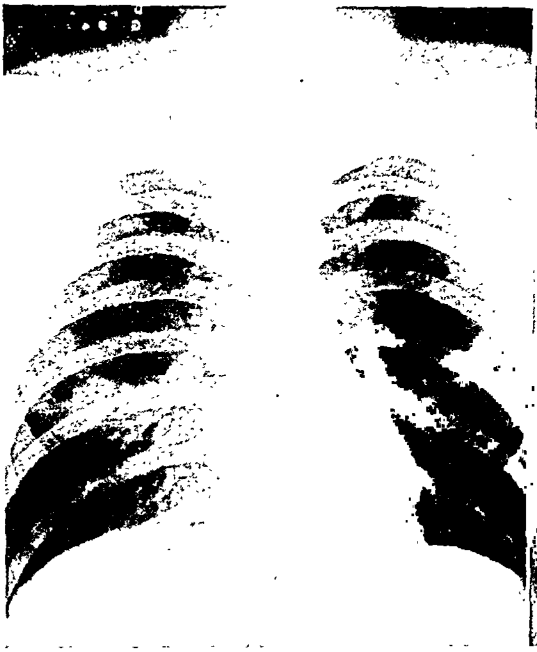

Fig. 9.

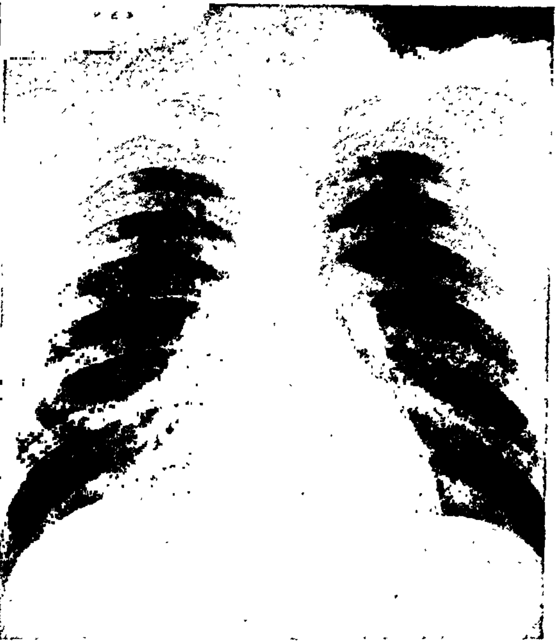

Fig. 10.

Fig. 9.—Case 6. Metastatic embryonal carcinoma in teratoma 6 months after orchiectomy and postoperative irradiation.

Fig. 10.—Case 6. Normal appearance of chest 3 years after roentgen therapy for metastatic embryonal carcinoma.

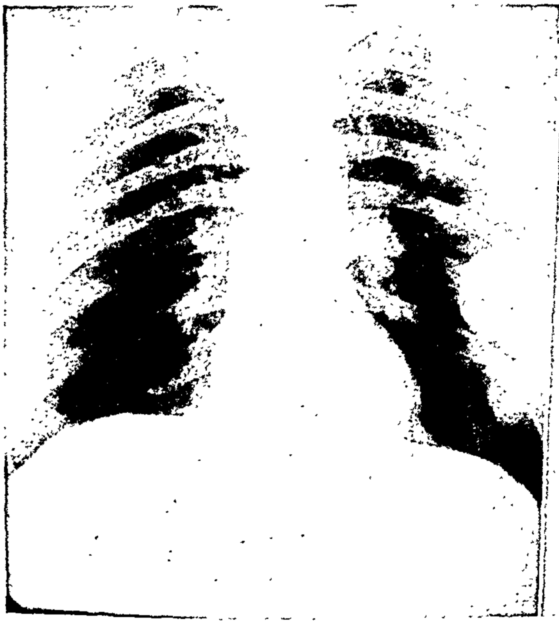

Fig. 11.

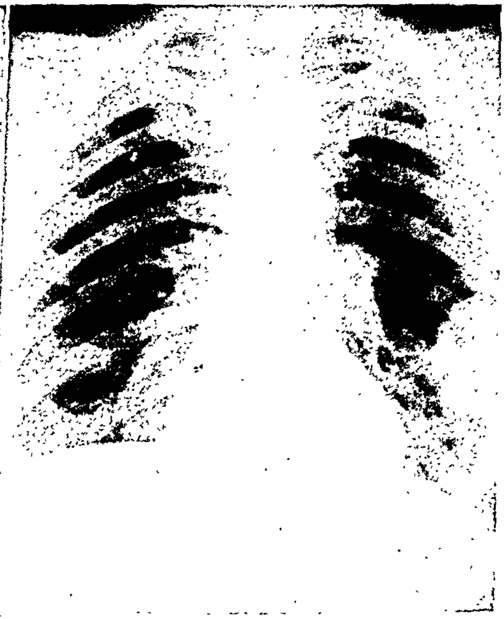

Fig. 12.

Fig. 11.—Case 7. Metastatic interstitial cell carcinoma of the testis, 6½ years after orchiectomy.

Fig. 12.—Case 7. Metastatic nodules with evidence of enlargement during the 6-month interval since Fig. 11 was made.

teratoma. One year prior to initial admission at the Tumor Institute, he had noted bilateral gynecomastia which had progressed until the enlarged breasts were of definite female appearance. Six months prior to admission, three circumscribed pulmonary metastases in the left lower lung were discovered (Fig. 11). These had increased slightly in size in this interval (Fig. 12). At time of admission, the Aschheim-Zondek test was negative. Twenty-four-hour urine 17 ketosteroids were 12.2 grams. The test for FSH was negative at about six mouse units with no definite end point reached. The tracheobronchial tree was normal at bronchoscopy. Two and one-half years ago, lingulectomy and wedge resection of the posterior basal segment of the lower lobe of the left lung were performed. The well-circumscribed tumors measured 8 by 6 by 3 cm. and about 2 cm. in diameter in the lingula, and 6 by 3 by 2 cm. in the posterior basilar segment. The pathologic diagnosis was metastatic interstitial cell carcinoma in the lung. Presently, this patient is without evidence of disease. The gynecomastia has partially resolved in the interim.

DISCUSSION

Presentation of these cases is not an endorsement of ill-considered onslaughts on pulmonary metastases. Usually, the appearance of a pulmonary metastasis, regardless of possible control of the primary lesion and the interval preceding the clinical appearance of the metastasis, is considered synonymous with incurability. In each of these 7 cases, representing varying forms of cancer in patients of varying ages, treatment of the pulmonary metastases has been of value in the management of the patient, whether or not permanent clinical freedom from disease has been accomplished. The 2 young men with testicular neoplasms (Cases 5 and 6), both with young families, have had 2½ to 3 years of good health since the treatment of the metastases. Two women (Cases 1 and 2) remain well 6 and 11 years, respectively, after treatment of this usually fatal development. One man (Case 3) has remained functional for 5 years after pulmonary resection for intractable hemoptysis, although he is not considered free of disease. In Case 4, the accomplishment is open to question, although the patient was asymptomatic for 6 months until sudden terminal illness with cerebral metastasis.

These cases illustrate the vagaries constantly present in the evaluation and treatment of patients with malignant tumors and they again emphasize the necessity for treating each patient upon an individual basis.

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POSTOPERATIVE EAR OXIMETER STUDIES ON PATIENTS WHO HAVE UNDERGONE PULMONARY RESECTION

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THIS STUDY was undertaken to determine the effect of pulmonary resection on the blood oxygen saturation of patients during the postoperative period. We also wanted to see if this measure of oxygenation could be correlated with clinical findings, and to determine whether ear oximeter readings would indicate the status of pulmonary function following thoracotomy. It was also thought desirable to see if the use of the ear oximeter could be of value in predicting impending complications, before more cumbersome diagnostic aids were used.

Maier and Cournand[1] reported, in 1943, a series of 38 patients, on whom arterial blood oxygen saturation was done after pulmonary resection, by the Van Slyke and Neill[2] manometric method. In 1954, Björk and Hilty[3] reported a series of 32 patients, on whom the arterial blood oxygen tensions were determined by the method of Riley, Proemmel, and Franke[4] after pulmonary resection.

These reported studies are rather difficult technically, and the blood samples were taken at irregular intervals during the postoperative period. The direct-reading ear oximeter,† which was used in our study, is relatively simple to operate, requiring only about 5 to 7 minutes per patient to obtain the blood oxygen saturation. The method is painless and of little bother to the patients. If one appeared daily before a postoperative patient to do an arterial puncture, considerable objection to that procedure probably would develop before 10 days had passed. Our study appeared more practical, and we were able to do tests for all 62 patients daily, and a few several times a day, with no resistance or objection at any time. In fact, a good number of the patients appreciated the extra care when the purpose of the test was explained to them!

Earl Wood,[5] in 1949, described the ear oximeter, which records absolute values accurate to within ±3 per cent. Stephen and co-workers[6] reported the

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average discrepancy between blood oxygen saturation as measured by the Van Slyke manometric method and the oximeter values at about ±2.5 per cent in 100 patients with normal circulation.

METHOD

The blood oxygen saturation was determined by ear oximetry daily for 10 days postoperatively in a series of 62 patients who had various types of resections for tuberculosis. In this series, most of the preoperative readings were taken just prior to induction of anesthesia, and after the patient had received only a belladonna derivative, usually scopolamine, for premedication. A few readings were taken the day prior to operation. The oximeter was used as a monitor during the operation, but these results are not included in this study. A reading was taken on each patient the afternoon of the operative day when the patient was awake and responding. Determinations were made at least once daily, usually between 3:00 P.M. and 4:00 P.M. or between 10:00 A.M. and 11:00 A.M. for 10 days.

Operations performed on these patients included 29 segmental resections, 20 lobectomies, 3 pneumonectomies, 2 decortications, 4 space-filling procedures, 1 closure of a bronchopleural fistula, and 3 open drainages. Two patients in this series died within the 10-day period. Five patients of the group studied had postoperative atelectasis, severe enough to require treatment.

The average blood oxygen saturation for normal subjects breathing room air is 97 per cent, ranging from 92 to 102 per cent. Our oximeter was calibrated on 12 normal subjects, breathing room air, and found to average 96.5 per cent.

RESULTS

The pre-induction readings in this series of patients ranged from 85 per cent to 100.5 per cent with an average of 93 per cent. The lower average in this series is attributed to lowered pulmonary function due to disease, rather than premedication. As a control, 38 patients with varying stages of pulmonary tuberculosis, who had not had thoracic operations, were checked by ear oximetry. The average in this control series was also 93 per cent, ranging from 88 to 97 per cent.

Oxygen, by nasal catheter, is routinely administered to our patients for a period of 12 to 24 hours postoperatively, and longer in a few patients requiring it. Accordingly, the readings taken on the operative day are generally higher, the average being 97 per cent. The lowest readings occurred on the second and third postoperative days, when the average was 89.5 per cent. The blood oxygen saturations then gradually returned to near normal levels, for this group of patients, and were at preoperative levels by the seventh to the tenth postoperative day.

DISCUSSION

In some cases these observations correlated well with other clinical such as x-ray and blood gas studies. The 5 patients who developed atel severe enough to require bronchoscopy or tracheal aspiration, had an average oximeter reading of 87 per cent on the second, third, and fourth days, and an average of 90 per cent on the fifth day, at which time the atelectasis usually had cleared. In other patients, the low readings could be accounted for by the fact that the patient had poor pulmonary function before and after operation. Some patients had severe pain during breathing, coughing, or moving and a very few low readings could be attributed to depressed respiration from the effect of opiates.

There were a few low oximeter readings for which the cause could not be determined. At the present time we are using the method of Alexander and Reydman,[7] described in 1953, for measuring the oxygen resaturation time in order to determine whether oxygen diffusion may be a factor in these unexplained low readings. We are also measuring the total and the timed vital capacities on the same patients during the postoperative period.

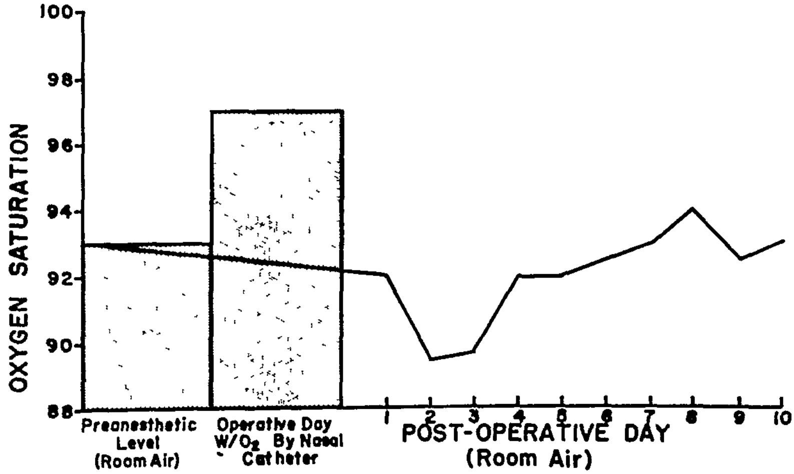

Fig. 1.—Average oxygen saturation (by ear oximeter) in patients after thoracic operations.

In most cases there seemed to be very little correlation between oximeter readings and pulse rates. Pulse rates varied with elevation of temperature, excitement, pain, and exertion. Hypoxia had to be quite severe before elevations in pulse rate occurred in these patients, most of whom were lying quietly in bed the first few postoperative days, except during the times they were encouraged to sit up, cough, and take deep breaths.

In conclusion, it was found that the blood oxygen saturation of this series of 62 patients was lowest on the second and third postoperative days with a gradual return to basal levels by the seventh or eighth day (Fig. 1). In patients who had obvious respiratory complications, the readings were below average.

It is thought the ear oximeter can be useful as a guide in evaluating pulmonary function in the postoperative period following thoracotomy. We found occasional instances in which severe pulmonary complications could be predicted from the oximetry readings. Oximetry does not indicate a specific diagnosis, and there were instances in which patients exhibited low oxygen saturation when we were unable to discover any pulmonary or circulatory complications.

Further studies, including other pulmonary function tests, are in progress in an effort to determine the cause of these few unexplained low blood oxygen saturations.

SUMMARY

Sixty-two patients undergoing intrathoracic operations were studied in regard to arterial blood oxygen saturation. These were made by means of an ear oximeter for 10 days following operation. The second and third postoperative days produced the lowest readings, with return to normal values by the seventh to the tenth day.

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also page

THE SURGICAL TREATMENT OF CHRONIC PLEURAL EMPYEMA

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IN RECENT years the prognosis of chronic pleural empyema has improved to a remarkable extent. Although much of this improvement is attributable to the use of potent antibacterial agents, other factors undoubtedly have contributed to these results. In attempting to evaluate some of these factors, one discovers that it is difficult to gain an adequate perspective from recent reports,[1-12] as they are generally limited in scope and occasionally controversial. As it seemed likely that the experience in a hospital for thoracic disease might provide such information, it was decided to review the cases of chronic empyema treated surgically at the Ray Brook State Tuberculosis Hospital between Jan. 1, 1950, and Oct. 1, 1957.

To provide a basis for comparison, both tuberculous and pyogenic empyemas were included in this study. Several sterile empyemas were also included. Patients treated merely by thoracentesis or surgical drainage were excluded. Thus, there were available for study 45 patients treated by 56 definitive surgical procedures. Thirty-nine patients had pulmonary or pleural tuberculosis at one time or another. The remaining 6 patients had, in addition to empyema, the following diseases: 1, cystic disease of the lung; 1, bronchogenic carcinoma; 1, spontaneous pneumothorax; 2, pyogenic pneumonia; and 1, pulmonary disease of undetermined etiology. The empyemas followed thoracotomy in 29 instances; 9 complicated therapeutic or spontaneous pneumothorax; and 10 were primary. When first bacteriologic studies were performed at Ray Brook, 23 empyemas yielded tubercle bacilli, 8 yielded mixed tuberculous and pyogenic organisms, 11 yielded pyogenic organisms, and 3 yielded purulent material sterile on culture. The pyogenic infections usually included staphylococci. By the time the surgery listed in Table III was undertaken, the number of tuberculous and mixed tuberculous and pyogenic infections had decreased to 16 and 7, respectively; and the number of pyogenic infections and sterile pleural spaces had increased to 13 and 9, respectively.

Bronchopleural Fistula.—Bronchopleural fistula was present at one time or another in 34 of the 45 patients. Bronchopleural fistula seemed to have no effect upon the results of treatment, often healing spontaneously with adequate drainage or drug therapy. Except in pulmonary decortication where leakage of air from the lung could interfere with postoperative pulmonary expansion,

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it seemed to matter little whether or not bronchopleural fistulas were sutured, provided the pleural space was obliterated and adequate amounts of tissue were available to cover the fistula. Pulmonary resection merely to eradicate a bronchopleural fistula is not considered necessary.

Types of Infection.—It is interesting to note that of the 7 patients with mixed tuberculous and pyogenic empyema at the first bacteriologic examination, 6 had already been subjected to thoracotomy and 1 had received a recent bronchogram, a possible source of contamination of the pleural cavity. Of the 14 patients with pure pyogenic empyemas at the first bacteriologic examination, 11 had been submitted to previous chest surgery. These findings are especially interesting since we have observed pleural spaces communicating with the bronchial tree for prolonged periods without detecting evidence of infection.[13] It would appear, therefore, that secondary pyogenic infection is frequently iatrogenic, a belief which is certainly not new.

From Table I it may be inferred that tuberculous empyemas frequently can be rendered sterile by drug therapy alone. Almost all will respond favorably to drug therapy combined with adequate surgery. On the other hand, surgery without adequate antituberculous drug therapy is not often successful.

TABLE I. DRUG REGIMENS EMPLOYED WITH SURGERY IN THE TREATMENT OF TUBERCULOUS AND MIXED EMPYEMAS

EFFECTIVE DRUG REGIMENS	NUMBER OF EMPYEMAS TREATED	EMPYEMAS YIELDING CULTURES NEGATIVE FOR TUBERCLE BACILLI	
		BEFORE DEFINITIVE SURGERY	AFTER DEFINITIVE SURGERY
PAS	1	0	1
INH	4	1	1
SM, PAS	4*	2	2
SM, INH	2	1	1
PAS, INH	4	2	2
SM, PAS, INH	2	1	1
INH, cycloserine	1	1	0
PZA	6	0	4
VIO	1	0	0
VIO, PZA	4†	0	3
VIO, cycloserine	1	0	1
No drugs	4	0	1
Total	34	8	17

PAS—para aminosalicylic acid. INH—isoniazid. SM—streptomycin. PZA—pyrazinamide. VIO—viomycin.

*One patient received these drugs only by instillation into the pleural cavity.

†One patient had previously received 4 months of pyrazinamide.

The prognosis for mixed tuberculous and pyogenic empyema is no longer as poor as it was prior to the introduction of antituberculous drug therapy. The presence of secondary pyogenic infection does not seem to affect the response of the tuberculous infection to antituberculous drug therapy. In Table II the apparent superiority of the results of treatment of tuberculous compared with mixed infections can be explained upon the basis of drug regimens and of surgery employed.

Table II. Results of Treatment

BACTERIOLOGY OF EMPYEMA PRIOR TO TREATMENT	NUMBER OF PATIENTS	CONDITION AT LAST EXAMINATION				DEAD
			RESULTS OF CULTURES			
		CURED	MIXED EMPYEMA	TUBERCULOUS EMPYEMA	PYOGENIC EMPYEMA	
Tuberculous	23	19		1	1	2*
Pyogenic	11	11				
Mixed	8	4	1		1	2*
Negative culture	3	3				
Total	45	37				4

*Only one patient died of causes directly related to tuberculosis.

Chronic pyogenic empyemas in our experience have rarely been rendered permanently sterile by drugs as long as a pleural space existed. This may have been due to the early appearance of drug-resistant organisms. On the other hand, these empyemas have been cured easily by surgery with little or no antibacterial therapy, provided the surgery obliterated the pleural space.

Antituberculous Drug Therapy.—Antituberculous drug therapy is reviewed in Table I. Effective drugs are defined as drugs to which tubercle bacilli are susceptible. Organisms are considered susceptible if they do not grow in the presence of drug in vitro or if the patient has not received the drug previously. Concentrations of drug employed are 10 mcg. of streptomycin, 10 mcg. of para-aminosalicylic acid, and 5 mcg. of isoniazid. Sensitivities to pyrazinamide, viomycin, and cycloserine are not performed routinely. Although there are too few cases to provide statistical information regarding the various regimens, it is evident that it was possible to render the empyemas noninfectious with drugs alone in many instances. One is impressed by the fact that, in these instances, isoniazid was almost always one of the drugs employed. This seems to support some of the recently published opinions regarding the superiority of isoniazid in combination with other drugs.[1, 15]

Complications and Mortality.—Serious postoperative complications consisted of massive intrapleural hemorrhage and contralateral spontaneous pneumothorax, both in the same patient. This patient later died of progressive pulmonary tuberculosis and mixed tuberculous and pyogenic empyema. One additional patient died of similar causes. It is believed that these fatalities are attributable to the use of a poor drug regimen in one instance (viomycin), and early cessation of effective drug therapy in another instance (patient left the hospital 2 weeks postoperatively). One patient died of cor pulmonale before her mixed empyema could be cured. Another patient with tuberculous empyema died following abdominal surgery for ulcerative colitis. The immediate cause of death was hemorrhage from a gastric ulcer.

Surgical Considerations.—Surgery was performed in 56 instances. The various types of surgery are listed in Table III. Standard thoracoplasty consisted of subperiosteal removal of the ribs over the empyema space. Polyethylene beads were inserted subcostally in the plombage thoracoplasties. The modified Schede procedures were generally similar to the type described by

TABLE III. RESULTS OF DEFINITIVE SURGERY

PROCEDURE	NUMBER OF OPERATIONS	RESULTS OF CULTURES OF EMPYEMA AT OPERATION				CONDITION AT LAST EXAMINATION*					DEAD
		STERILE SPACE	MIXED EMPYEMA	TUBERCULOUS EMPYEMA	PYOGENIC EMPYEMA	CURED	STERILE SPACE	MIXED EMPYEMA	TUBERCULOUS EMPYEMA	PYOGENIC EMPYEMA	
Standard thoracoplasty	9	2	1	6		5	1		2		1
Plombage thoracoplasty	2			2		1			1		
Modified Schede	15	1	2		12	13		1		1	
Decortication	9	3	1	4	1	8					1
Decortication and thoracoplasty	4	2			2	2	1			1	
Decortication and resection	8	2	1	4	1	5			1	1	1
Decortication, resection, and thoracoplasty	3	1		2		3					
Plastic procedure	6		2	1	3	4				1	1
Total	56	11	7	19	19	41	2	1	4	4	4

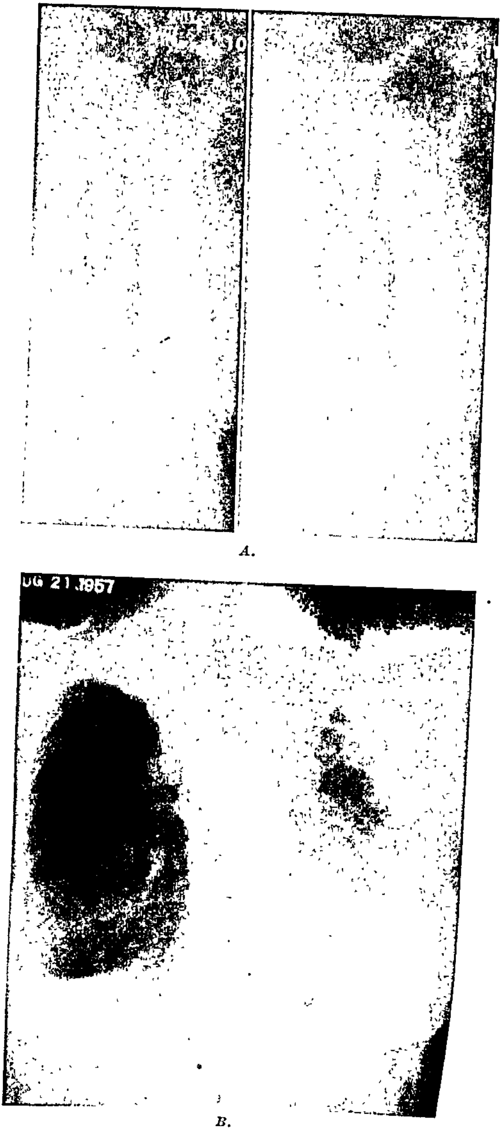
*Some of the failures were later cured by other procedures.

Grow.[16] Pulmonary decortication was performed both with and without removal of the parietal pleura. Occasionally, pulmonary resection was employed in combination with some other procedure. Two successive procedures were performed on 8 patients, and 3, on 3 patients.

To be successful, definitive surgery should obliterate the pleural space. A persistent pleural space, even if sterile, is a potential invitation to infection. Standard and plombage thoracoplasty are of limited value, and are useful only when the walls of the empyema are not very rigid. Plombage thoracoplasty is occasionally complicated by infection in the subcostal space. On the other hand, the Grow modification of the Schede procedure can be used with little fear of deformity and with excellent results; being confined to the diseased area, it is well tolerated by the poor-risk patient. It can be performed in stages, or repeated, should the first procedure fail to achieve the expected result. It is important to remove foreign bodies such as surgical silk or calcium deposits, as these may be a source of chronicity. A simple method of removing calcium is curettage. The wound may be sutured almost completely at the time of surgery. Adequate drainage should be maintained with a soft rubber tube until the empyema space has obliterated itself from the depths outward. A pressure dressing for several weeks will foster early obliteration of the space.

Decortication has proved most useful in expanding lungs which contain little disease and where the empyemas have been of relatively short duration or small size. Appreciable pulmonary fibrosis is a well-known cause of poor postoperative re-expansion. Long-standing empyema may involve the underlying lung so as to produce a similar effect and, if the empyema involves a large proportion of the lung surface, postoperative re-expansion of the lung may be poor. On the other hand, if the empyema involves only a small portion of the lung surface, the remaining lung will often expand appreciably if it is completely freed, including the fissures. A poorly expansile lung may be useful as a space filler (Fig. 1). For this reason resection of such a lung is rarely performed with decortication, except for indications applicable in the absence of empyema. Although parietal decortication would seem generally desirable, it does not appear necessary to effect a cure of empyema. Parietal pleura may be allowed to remain if one wishes to minimize blood loss. Occasionally in these instances pleural symphysis may be delayed, but this does not seem serious. Pulmonary expansion following decortication appears to have no ill effects upon pulmonary tuberculosis, provided adequate antituberculous therapy is administered.

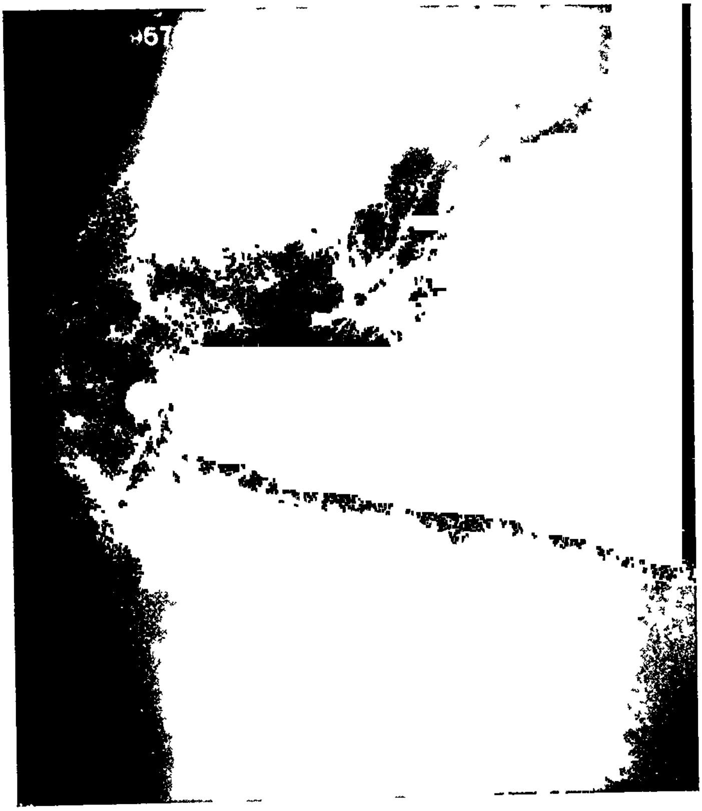
It has been found useful to employ a number of technical aids when performing decortication. As in other types of pulmonary surgery, the Bovie coagulation unit is an excellent hemostatic agent. A 2-inch dental type mirror often exposes to vision the most remote recesses of the pleural cavity. A curved pair of scissors (Fig. 3) can be used to cut *"around corners,"* with or without the aid of the mirror. In a number of instances, 2 or even 3 separate intercostal incisions at different levels have provided excellent exposure to otherwise inaccessible portions of the pleural cavity.



A.

B.

Fig. 1.—Successful decortication for mixed tuberculosis and pyogenic empyema *illustrating* use of a poorly expansile lung as a space-filler. About one year postoperatively, *the vital* acity had increased by 8 per cent of the preoperative value. *A*, Preoperative *tomogram.* Postoperative roentgenogram.



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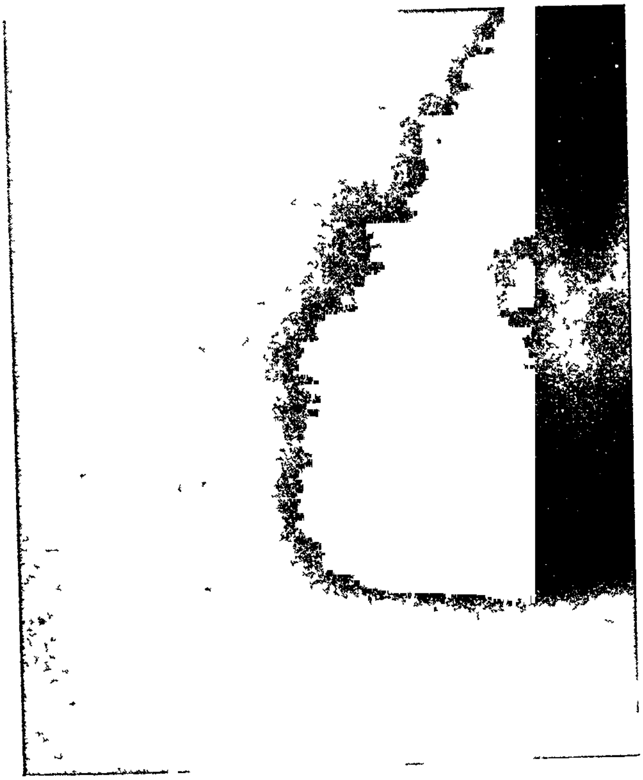

B

Fig 2.—Successful obliteration of a mixed tuberculous and pyogenic empyema by a modified Schede thoracoplasty. *A*, Preoperative bronchogram indicating bronchopleural fistula *B*, Preoperative lateral tomogram outlining the empyema space.

TABLE IV. EFFECT OF DECORTICATION UPON VITAL CAPACITY

PATIENT	EXTENT OF DECORTICATION	VITAL CAPACITY			
		PRE-OPERATIVE (C.C.)	POST-OPERATIVE (C.C.)	POST-OPERATIVE INTERVAL IN DAYS	PER CENT POST-OPERATIVE CHANGE
L. B.	Visceral + parietal	2,000	1,000 to 2,550	6 to 366	−50 to +28
C. M.	Visceral + parietal	2,200	2,900	23	+20
I. B.	Visceral + parietal	1,200	1,100 to 1,300	30 to 690	−8 to +8
G. G.	Visceral + parietal	2,200	2,200 to 2,200	22 to 444	0
M. M.	Visceral	1,500	1,450 to 1,800	29 to 151	−3 to +20
L. G.	Visceral	1,900	2,000 to 2,800	41 to 447	+5 to +48
L. S.	Visceral	2,300	2,600 to 3,000	15 to 56	+13 to +30
F. B.	Visceral + lobectomy	1,400	1,100 to 1,400	74 to 362	−21 to 0
C. W.	Visceral + lobectomy	3,100	2,400 to 2,600	27 to 43	−33 to −16

Function.—The effect of pulmonary decortication upon vital capacity is shown in Table IV. From this data, functional superiority cannot be claimed for visceral and parietal decortication. As indicated by Patton and associates,[9] the amount of functional gain after decortication is related to the relative increase in expansion of the lung operated upon. The early postoperative vital capacity represents the difference between the depression of ventilation caused by the "thoracotomy effect"[17, 18] and the improvement in ventilation due to pulmonary re-expansion. In this group of patients, decortication alone was accompanied by a permanent increase in vital capacity in all but one instance. Furthermore, improvement in vital capacity occurred in 2 patients despite duration of pulmonary collapse of 22 years and 14 years, respectively.

Fig. 3.

Table V represents the effect on vital capacity of the various types of thoracoplasty employed to obliterate pleural spaces. It has been shown that thoracotomy produces a much more profound early depression of vital capacity.[18] Indeed, thoracoplasty performed to obliterate a rigid pleural space seems to have little effect upon vital capacity. There appears to be no correlation between changes in vital capacity and the number of ribs involved in the thoracoplasty procedures. This is to be expected since these procedures usually did not alter the rigidity of the visceral pleura, and they rarely collapsed functioning pulmonary tissue.

There appears to be little evidence to indicate that distention of pulmonary tissue of a degree encountered following decortication can cause emphysema.

Timed vital capacity following decortication[18] shows no early change. It has been interesting to discover well-developed bullous emphysema in several lungs which we have decorticated after they had been collapsed for many years. This would seem to indicate that, at least in these instances, intrapulmonary factors were more important than distention and that collapse did not prevent these factors from causing emphysema.

TABLE V. EFFECT OF THORACOPLASTY UPON VITAL CAPACITY

PATIENT	PROCEDURE (NUMBER OF RIBS)	VITAL CAPACITY PRE-OPERATIVE (C.C.)	VITAL CAPACITY POST-OPERATIVE (C.C.)	POST-OPERATIVE INTERVAL IN DAYS	PER CENT POST-OPERATIVE CHANGE
J. W.	Plombage (6)	2,700	2,110 to 2,200	1 to 54	−22 to −18
W. K.	Plombage (4)	1,600	1,400 to 1,600	15 to 240	−12 to 0
M. M.	Plombage (5)	1,400	1,300 to 1,400	3 to 143	−7 to 0
C. G.	Mod. Schede (9)	2,100	2 000	30	−5
W. K.	Mod. Schede (2)	1,550	1,500	36	−3
O. B.	Mod. Schede (2)	3,100	3,200 to 3,000	48 to 198	+3 to −3
E. C.	Standard (5)	1,650	1,550 to 1,700	4 to 28	−6 to +3
J. C.	Standard (5)	1,750	1 600 to 1,650	9 to 66	−8 to −6
F. T.	Standard (9)	1,100	1,000 to 1,400	29 to 215	−9 to +27
A. S.	Standard (2)	2,800	2,800 to 2,800	26 to 45	0
D. O.	Standard (3)	2,100	1,900 to 1,800	17 to 57	−9 to −14
C. M.	Standard (6)	2,400	2,000 to 2,100	7 to 31	−17 to −12
E. K.	Standard (10)	950	900 to 1,000	4 to 52	−5 to +5
I. R.	Standard (6)	950	1,000 to 1 000	15 to 304	+5

DISCUSSION

Recent publications appear to have overemphasized the value of decortication in the treatment of chronic pleural empyema. Undoubtedly there are many advantages in the use of decortication, especially ① improvement of function and ② avoidance of deformity. However, there are many instances in which a carefully performed thoracoplasty will accomplish the same functional and curative results as decortication. Perhaps the most important difference between decortication and thoracoplasty lies in the early postoperative ventilatory changes, which may be severely depressed after the former and is usually only slightly altered after the latter. Considerations such as these may influence a surgeon to prefer thoracoplasty to decortication in poor-risk patients.

Drug therapy is undoubtedly responsible for the excellent results of surgery for chronic tuberculous empyema. Surgery is relatively ineffective without such therapy. On the other hand, drug therapy may render tuberculous empyemas noninfectious; but, in many instances, surgery must be combined with drug therapy to effect a cure.

The treatment of chronic pyogenic empyema seems to be dependent more upon surgery than antibacterial agents. With little or no drug therapy, surgery can effect a cure in almost every instance. On the other hand, drugs in the presence of a persistent pleural space are rarely curative probably because of the rapid appearance of drug-resistant organisms.

SUMMARY

A review of almost 7 years' experience with chronic empyema reveals that with proper treatment the prognosis is excellent regardless of the type of infection Pulmonary decortication and the various types of thoracoplasty are all useful procedures The indications for these procedures are briefly discussed

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STRANGULATED DIAPHRAGMATIC HERNIA

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Diaphragmatic hernias are often considered relatively benign lesions which can be watched with impunity. However, complications do occur in a number of these patients and these can be very serious or even fatal. We, therefore, suggest that a more aggressive attitude be taken in treating this type of hernia. We are reporting here a survey, covering the 10-year period from Jan. 1, 1947, to Jan. 1, 1957, of all cases of strangulated diaphragmatic hernias at the John Gaston Hospital and the Baptist Memorial Hospital, Memphis, Tenn. One or 2 cases were excluded in which the diagnosis was not definitely established. Each hospital had approximately a 500 bed census during the 10-year period.

For the purpose of our paper we are considering a strangulated diaphragmatic hernia as one in which the hernial ring is constricting the herniated organ so as to compromise or cut off the blood supply, either venous or arterial, of the herniated organ or organs. By incarceration of a diaphragmatic hernia we mean that the herniated organs are so bound by adhesions that the hernia is irreducible by medical methods and that surgery is necessary for the reduction of such a hernia.

CASE REPORTS

Case 1.*—J. W., a white woman aged 74, was admitted Oct. 19, 1948, to the Baptist Memorial Hospital with a diagnosis of incarcerated diaphragmatic hernia. From her history it was evident that she had been known to have a hernia for 20 years as proved by numerous serial films. It was believed that the stomach and colon were in the left chest. For 20 years she had "eaten like a bird."

She had had symptoms of obstruction on numerous occasions, which would usually subside in a few hours after vomiting. Two days before her admission here she began to have left epigastric pain with some vomiting and she noticed she passed relatively little gas by rectum. She also noted the pain sometimes radiated to the left shoulder. On admission she was afebrile and her blood pressure was 120/80 mm. Hg. She was an elderly white woman appearing acutely ill, vomiting intermittently. The heart was normal. The right chest was clear. On the left, breath sounds were absent. The abdomen revealed some tenderness in the left upper quadrant, but no rigidity. A small amount of barium was given by mouth and it was demonstrated that only a small portion of the cardiac end of

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*This case was abstracted briefly by Dr. Duane Carr.[2]

the stomach was in the abdomen. Some of the barium could be passed into the supradiaphragmatic portion of the stomach by laying the patient in the prone position with the head down. None of the barium could be encouraged to proceed into the duodenum. The x-ray films also showed a portion of the colon in the left hemithorax.

Despite the fact that the patient's age and general condition created a greater than average risk, a left diaphragmatic herniorrhaphy was performed on Oct. 20, 1948, after proper preparation.

At operation, the stomach, colon, and a portion of the omentum were found herniated into the left hemithorax through a diaphragmatic opening which was approximately 8 cm. in diameter. The edge of the ring was markedly thickened and fibrotic. The posterior part of the diaphragm was very much attenuated and contained no muscle fibers. The thoracic portion of the stomach was hugely dilated and the loop of transverse colon which was also present in the thorax was adherent to the surface of the stomach. In the course of the operation a moderate amount of clear yellow peritoneal fluid was aspirated. The diaphragmatic hernial orifice was lateral to the esophageal hiatus and gave every appearance of being a congenital hernia. The stomach and colon were slightly dusky at first but the colon soon improved when the hernial ring was opened. The hernial sac was closed with interrupted sutures of No. 2-0 cotton. The weakened area posteriorly in the diaphragm was reinforced by imbricating the diaphragm upon itself. The excess portion of the hernial sac was excised. The thoracic wound was closed in layers using interrupted cotton sutures throughout. The patient received 2,500 c.c. of whole blood during and immediately after the operation and was returned to her room in good condition.

The patient tolerated the operation exceedingly well, her pulse rate at no time rising above 90. The blood pressure remained stable at about 126/66 mm. Hg. On Oct. 23, 1948, a left thoracentesis yielded 450 c.c. of thin bloody fluid. The patient had some mild abdominal distention and was slightly dusky at times and irrational. We later discovered that part of her disorientation was apparently due to small doses of Nembutal which were also causing insomnia. The symptoms subsided when the barbiturates were discontinued. She was discharged from the hospital on Nov. 19, 1948, one month after admission.

For the first time in over 20 years she could eat comfortably without regurgitation, and therefore for the first time in 20 years she was able to have meals with her friends instead of in the privacy of her own room. She has since gained 35 pounds in weight. Later studies showed the entire stomach beneath the diaphragm and in normal position. The patient has continued leading a normal life. It is now 9 years since her surgery and her present age is 83.

CASE 2.—I. L. B., a white woman, age 69. We first saw this patient Nov. 15, 1948. Her chief complaint was difficulty in swallowing, with pain in the lower chest while eating. For several years the patient had known she could not eat normally. She had to take her time in swallowing. For the 2 years preceding admission, she had noted severe pain in the lower mediastinal region, and the chest felt full after eating. She noted she had to belch during meals and also had some cough productive of heavy mucoid sputum after eating. She had noted some dyspnea with fatigue for several years, gradually becoming worse although there had been no weight loss. She had an incidental rectal stricture which had to be dilated periodically.

In the past she had had typhoid fever at the age of 16, an ulcer removed from the colon in 1931, a hemorrhoidectomy many years before, and a hysterectomy in 1932. A right nephrectomy had been performed in 1935. A tonsillectomy and antrotomy had also been performed years previously.

The physical examination was negative. The blood work was normal although the blood sedimentation rate was increased to 35 mm. in 1 hour, corrected for cell volume.

A chest film on Nov. 10, 1948, showed a normal lung, heart, and mediastinum with some calcification in the arch of the aorta. Behind the heart shadow cavity with walls about 1 cm. thick, and a fluid level in this space just above the diaphragm. The lateral film revealed the cystic cavity to be the stomach, or a portion of it, above the diaphragm in the posterior mediastinum.

Esophagograms on Nov. 15, 1948, showed the esophagus to be long and redundant, and the major portion of the stomach to be inverted in the lower mediastinum. A diagnosis of esophageal hiatal hernia was made, probably congenital. Because of her age, the loss of one kidney, and her extreme aversion to surgery, we felt an operation could be deferred until such time as she either had obstruction or began to lose weight. She did fairly well under medical management until April 8, 1950, when she was admitted to the hospital vomiting periodically, with some of the vomitus being black at times. She again refused major surgery.

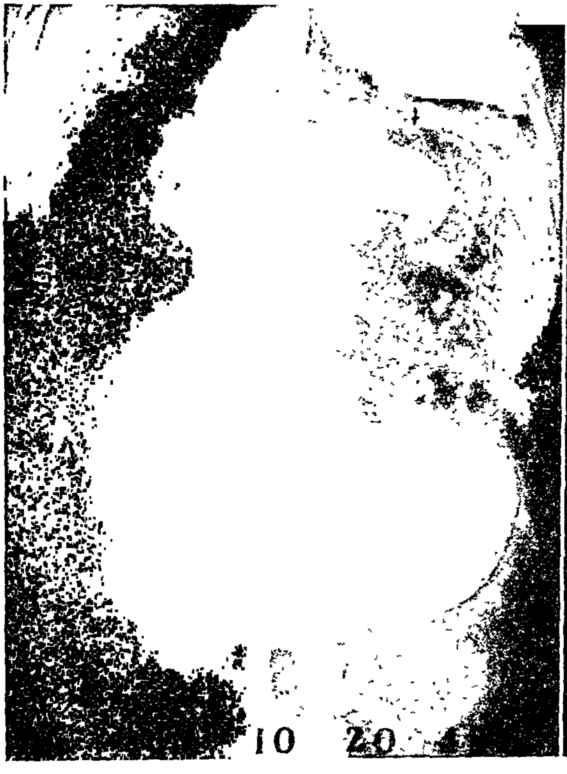


Fig. 1.

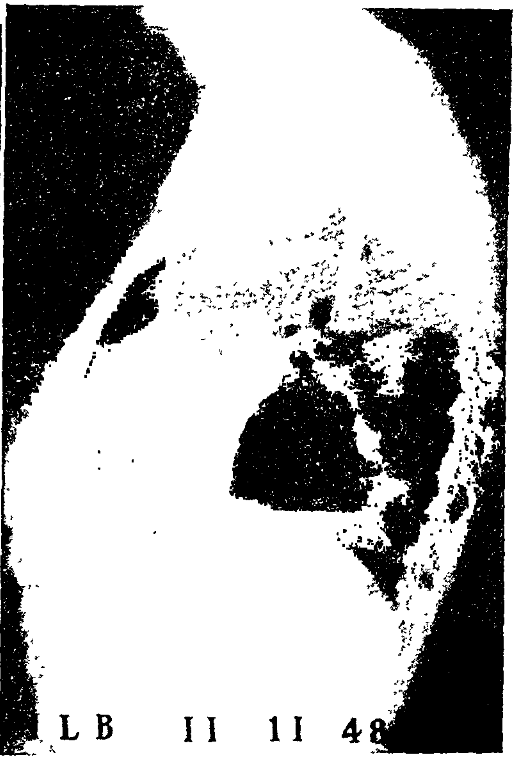


Fig. 2.

Fig. 1.—Case 2, I. L. B. Oct. 20, 1948. A barium swallow demonstrates most of the stomach in the left pleural space with considerable pleural reaction on that side also.

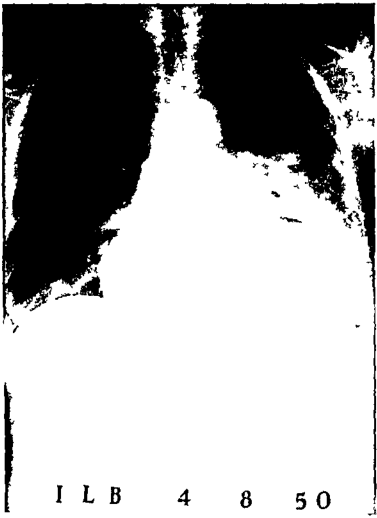
Fig. 2.—Case 2, I. L. B. Nov. 11, 1948. Left lateral chest film. There is a large space behind the heart with an air-fluid level characteristic of a hiatal hernia. The diagnosis can often be made from the lateral film alone.

A new chest film showed pneumonitis in the left mid-lung field. The electrocardiogram showed some left axis deviation. Because of the pneumonitis, surgical repair of the hernia was not insisted upon at the time. Instead, on April 17, 1950, a left phrenic crushing was performed resulting in a good paralysis of the diaphragm. Following that she had some improvement in her ability to swallow but she still had difficulty with foods that contained any coarse vegetable fibers. She was urged to grind all her meat and was instructed to take a teaspoon of Alcaroid after each meal containing meat.

She was next admitted to the King's Daughters' Hospital in Greenville, Miss., Oct. 24, 1950, with what was at first thought to be a heart attack. She was in shock at the time of admission. However, an electrocardiogram was normal except for some left axis deviation. She gave a history of having lost considerable weight in the preceding few months, although her usual symptoms from the hiatal hernia had been markedly relieved by the phrenic crushing. She was treated medically and gradually recovered

In 1951, the left diaphragm resumed motion and her symptoms increased On May 12, 1951, a left permanent phrenic nerve interruption was performed. In December, 1951, she had another attack of retained gastric contents and was treated by Wangensteen suction and intravenous fluids and made a recovery Fluoroscopic examination at that time showed most of the left diaphragm still paralyzed but there was a suggestion that a few fibers of the nerve were still carrying slight impulses to portions of the diaphragm

On April 27, 1953, barium studies revealed a large hiatal hernia with at least two thirds of the stomach in the chest The stomach was markedly dilated with kinking at the diaphragmatic hiatus, it was about half full of fluid The patient was clinically better at this time, however, than formerly, although she still had occasional dyspnea and intermittent strangulation of the stomach



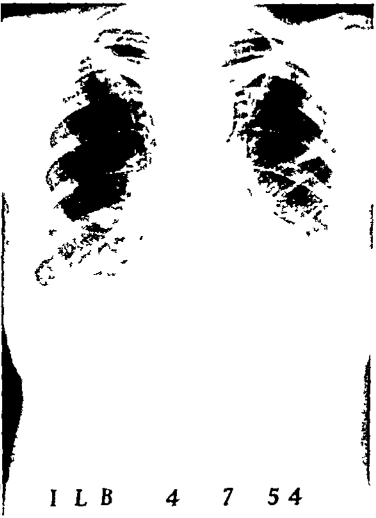


Fig 3

Fig 4

Fig 3—Case 2, I L B April 8 1950 The large hiatal hernia shadow merges with the heart shadow and an air-fluid level is seen in the left mid chest area which is really in the stomach In addition there is an aspiration pneumonitis in the left lung This type of aspiration pneumonitis is common with hiatal hernia and is a very good reason for repairing these hernias before repeated pneumonitis produces permanent pulmonary crippling

Fig 4—Case 2, I L B April 7, 1954 Postoperative film with the stomach now in the abdomen The left diaphragm is slightly elevated as a phrenic crush was done at the time of surgery to take stress off the suture line There is some residual pulmonary fibrosis in the left lung particularly from the repeated attacks of aspiration pneumonitis The patient was clinically well at this time

In January, 1954, she had a "virus infection" in the lungs with considerable cough and yellowish sputum occasionally streaked with blood She was placed on a passive bronchial drainage routine, and received antibiotics, with improvement.

On Jan 12, 1954, she was re admitted to the Baptist Memorial Hospital with presumably another moderate small meat impaction which responded to medical therapy, including frequent sips of Alcaroid in water, and antispasmodics The patient wore dentures and cavity with walls about 1 cm. thick, and a fluid level in this space just above the diaphragm. The lateral film revealed the cystic cavity to be the stomach, or a portion of it, above the diaphragm in the posterior mediastinum.

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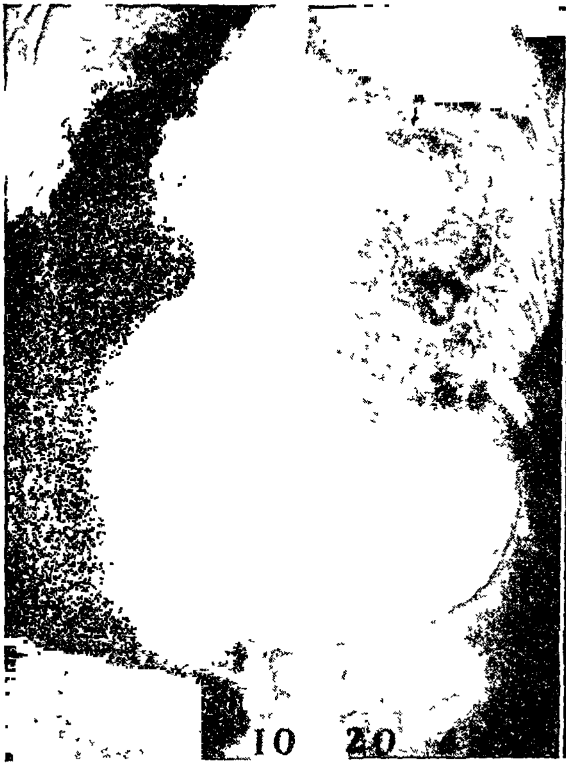

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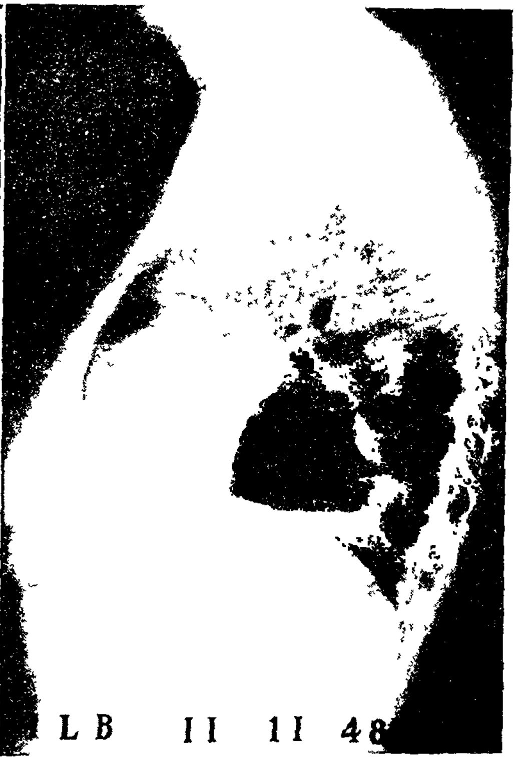

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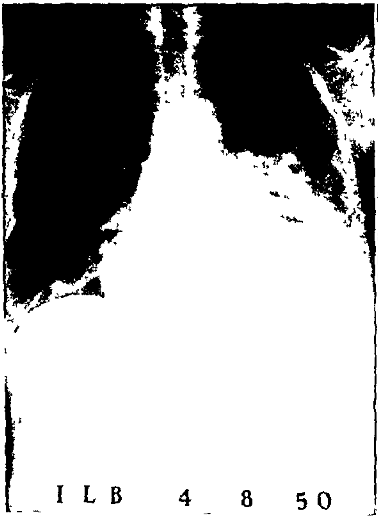

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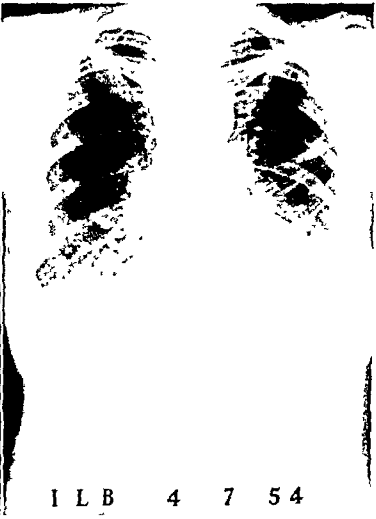

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On Jan. 12, 1954, she was re admitted to the Baptist Memorial Hospital *with presumably* another moderate small meat impaction which responded to medical therapy, including frequent sips of Alcaroid in water, and antispasmodics. The patient wore dentures and was unable to chew her meat completely. Whenever she ate meat which was not ground, she had spells of impaction or strangulation. On Feb. 7, 1954, she was re-admitted to the Baptist Memorial Hospital with a partially strangulated hiatal hernia. Her clinical condition did not improve and on Feb. 15, 1954, the diaphragmatic hernia was repaired.

At operation a large sliding hiatal hernia was present with part of the stomach and some omentum in the chest. The phrenic nerve was crushed just above the diaphragm. There were rather dense adhesions present between these organs and the hernial sac itself. These were dissected free and the abdominal contents replaced in the abdomen. Most of the sac was excised and part of the sac was used to reinforce the repair behind the esophagus. The diaphragm was slit anteriorly 3 cm. from the esophagus to slide the esophagus forward into a higher position on the diaphragm. The diaphragm was closed behind the esophagus using interrupted sutures of No. 2-0 cotton. The esophageal external wall musculature was then stitched to the diaphragm with interrupted sutures of the same material. Penicillin, 500,000 units, and 1 Gm. of streptomycin were placed in the pleural space and two intercostal tubes were inserted; one in the eighth interspace in the posterior axillary line and the other in the fifth interspace in the anterior axillary line and later connected to a water trap bottle. The incision was closed in layers. The postoperative condition was good and her convalescence was uneventful.

On Aug. 10, 1956, she was hospitalized in the Baptist Memorial Hospital under the care of Dr. Henry Rudner, Sr., with an acute coronary thrombosis from which she slowly recovered. A chest film showed the stomach still in the abdomen beneath the diaphragm. In June, 1957, she reported feeling fine and eating a regular diet without difficulty.

Case 3.—E. B., a Negro man aged 30, was first admitted to the John Gaston Hospital on Oct. 2, 1943, for presumed intestinal obstruction. At that time, x-ray studies showed a density in the left lower lung field which was located anterolaterally. Barium studies of the upper gastrointestinal tract were normal. A barium enema was not done. He became asymptomatic and was discharged on Oct. 22, 1943.

He was next admitted to the John Gaston Hospital on May 16, 1945, with a history of lower abdominal pain, vomiting, and obstipation of 24 hours' duration, despite administration of oral Epsom salts. The physical examination was negative except for lower abdominal tenderness. Laboratory studies were within the normal range. An exploratory operation was performed on May 15, 1945, through a right paramedian incision with the preoperative diagnosis of small bowel obstruction. At operation a 4 cm. defect was found in the left leaf of the diaphragm, through which the entire greater omentum, transverse colon, and strangulated loops of small intestine had herniated, without a sac. The diaphragmatic opening was enlarged and the hernia reduced. The diaphragm was closed with interrupted silk sutures and the abdominal wound closed in layers.

The patient ran a febrile course and died on May 23, 1945, on the seventh postoperative day. An autopsy revealed massive atelectasis of both lungs.

Case 4.—J. P., a 28-year-old Negro man, was admitted in shock to the John Gaston Hospital on Aug. 3, 1955, with multiple knife lacerations of the chest wall, right arm, and abdominal wall. Numerous x-ray studies of both chest and abdomen were negative. He was discharged on Aug. 6, 1956.

He was re-admitted on Jan. 10, 1956, with a history of abdominal pain of 6 hours' duration. This was accompanied by nausea and vomiting. Physical examination and laboratory studies were within normal limits. The only significant finding was patchy consolidation in the left base shown in chest films on admission. Subsequent x-ray studies revealed intestinal obstruction and probably a left diaphragmatic hernia.

At operation on Jan. 15, 1956, through a thoracoabdominal incision, utilizing the left sixth intercostal space, the greater omentum was found incarcerated through an opening in the parietal pleura at the eighth left intercostal space in the anterior axillary line. This was due to a diaphragmatic hernia anteriorly at the periphery of the diaphragm. The hernial opening measured 4 cm. in diameter and through it protruded the splenic flexure, the left half of the transverse colon (which was partially strangulated), and the greater omentum The hernia was reduced by incising the greater omentum, making it possible to replace the colon in the abdominal cavity The diaphragm was closed with interrupted silk sutures and the incision closed in layers Postoperatively the patient became markedly distended to the point that it was necessary to perform a laparotomy Jan 17, 1956, and cecostomy for decompression Following this procedure he made an uneventful postoperative recovery and was discharged on Feb 4, 1956 He was last seen in the outpatient department on March 8, 1956, at which time he was asymptomatic

CASE 5 —J G, a 52 year old Negro man, began to have severe abdominal pain approximately 18 hours prior to his admission to the John Gaston Hospital on March 10, 1947 The pain, which began in the right lower quadrant, soon became localized in the left upper quadrant There was vomiting numerous times following the onset of the pain There was no history of previous trauma either to the abdomen or chest Physical examination revealed a temperature of 98 2° F, respiratory rate of 28, and a blood pressure of 60/50 mm Hg He was obviously in profound shock, apprehensive, and perspiring profusely Significant findings were a tachycardia, abdominal tenderness mostly in the left upper quadrant, and a few audible peristaltic sounds Laboratory studies showed a red cell count of 5,040,000 and a white cell count of 14,600 with a shift to the left The urinalysis was not remarkable except for a proteinuria of 2 plus, the blood NPN was 56 mg per cent on admission

On x ray studies of the chest, the diaphragm on the left could not be identified The colon was not displaced Films made after the passage of a nasogastric tube indicated rotation of the stomach upward into the left hemithorax The intestinal pattern suggested that a portion of small intestine was present in the left chest A diagnosis of strangulated left diaphragmatic hernia was made

The patient was operated upon on March 10, 1947, through a left thoracoabdominal incision through the eighth intercostal space Ninety centimeters of gangrenous small intestine were removed from the left chest and resected, and an end to end anastomosis performed The diaphragmatic opening in the central portion of the left leaf was closed with interrupted sutures The incision was closed in layers with closed intercostal tube drainage employed in the left hemithorax

Postoperatively the patient had a very stormy course with high fever On the seventh postoperative day he eviscerated The evisceration was reduced and closure accomplished with through and through sutures, but he died on March 18, 1947, shortly after the procedure An autopsy was not permitted

CASE 6 —F O, a 31 year old male Mexican was admitted to the John Gaston Hospital Oct 7, 1947, with a history of epigastric pain, nausea, and vomiting of 3 days' duration The only significant physical finding was left upper quadrant and epigastric tenderness

Laboratory studies showed a leukocytosis with a shift to the left X ray studies of the chest showed the left diaphragmatic outline to be indistinct and an air fluid level present in the lower left base A film of the abdomen revealed marked dilatation of the transverse colon

With a diagnosis of strangulated or incarcerated left diaphragmatic hernia, an exploratory operation was made on Oct 8, 1947, through a left rectus incision which was extended into a thoracoabdominal incision through the eighth left intercostal space Through a 2 5 cm opening posterolaterally in the diaphragm, 25 cm of transverse colon had herniated and had become strangulated The hernia was reduced and the diaphragmatic opening closed with interrupted cotton sutures The incision was closed in layers His postoperative course was uneventful and he was discharged Nov 3, 1947

CASE 7 —W D, a 50 year old Negro man, was first admitted to the John Gaston Hospital Aug 11, 1946, with a pistol bullet wound of the left chest He ran a febrile course until intercostal drainage was established, with evacuation of a left empyema cavity Following this procedure his recovery was rapid and uneventful

He was next admitted on Jan. 15, 1955, with a history of pain in the chest, vomiting, and constipation of 4 days' duration. On physical examination there was limited chest expansion bilaterally. There was a palpable friction rub over the left lateral chest wall, and breath sounds were absent over this area. The abdomen was markedly distended, tympanitic, and silent. Laboratory studies revealed a hemoconcentration, leukocytosis, and an elevated blood NPN (140 mg. per cent). A chest roentgenogram showed a small intestinal obstruction, and an elevation of the left leaf of the diaphragm with atelectasis at the left base.

An exploratory operation was performed on Jan. 16, 1955, through a left thoracoabdominal incision, on a preoperative diagnosis of strangulated diaphragmatic hernia. At operation, 20 cm. proximal to the ileocecal valve, a 25 cm. segment of terminal ileum was found to be strangulated through a 4 or 5 cm. opening slightly posterior to the dome of the diaphragm. This segment, which was necrotic and liquefied, was resected and an end-to-end anastomosis of the terminal ileum performed. During the procedure the patient had a cardiac arrest which responded to cardiac massage and the procedure was quickly terminated. Postoperatively the patient did not breathe spontaneously. He died 40 hours following completion of the procedure on Jan. 18, 1955. Autopsy was obtained and confirmed the above findings.

Case 8.—R. S., a 34-year-old Negro man, was first admitted to the John Gaston Hospital, Nov. 4, 1945, with a stab wound of the left anterolateral chest wall in the sixth intercostal space. He was observed for possible cardiac stab wound and treated with bed rest until his discharge Nov. 23, 1945. Numerous x-ray and fluoroscopic examinations were reported to be negative.

He was re-admitted to the hospital on Oct. 30, 1951, with an unobtainable blood pressure and a feeble pulse with a rate of 100. He had begun to vomit approximately 36 hours prior to admission and stated that his vomitus was coffee-ground in color. Other findings were absence of breath sounds over the left lower chest and a soft abdomen. Laboratory studies showed a marked hemoconcentration, with an hematocrit of 63 per cent, and a red cell count of 7,800,000. The urinalysis showed a three plus pyuria and proteinuria. Fluoroscopy and barium studies of the gastrointestinal tract revealed an incarcerated diaphragmatic hernia.

At surgery, on Oct. 31, 1951, a left thoracoabdominal incision through the eighth intercostal space was employed. The distal 80 per cent of the stomach along with the entire greater omentum had herniated through a defect in the left diaphragm and had become strangulated. No hernial sac was present. The stomach and omentum were replaced in the abdomen. The diaphragm was closed with interrupted cotton sutures and the incision closed in layers. Closed intercostal drainage was employed in the left pleural space. Postoperatively, the patient became anuric with rising blood NPN to 370 mg. per cent at the time of his death on Nov. 3, 1951. Autopsy was not granted.

Case 9.—T. L. R., a 36-year-old white man, was admitted to the Baptist Memorial Hospital on Sept. 19, 1956, because of colicky epigastric pain present for 12 hours prior to admission. He stated that he had been stabbed with a pair of short nail scissors over the left chest about 2 years previously. He had been a patient in the Baptist Memorial Hospital at that time but went home 48 hours after admission with no treatment other than observation. In July, 1956, he was hospitalized in the Methodist Hospital, Memphis, Tenn., for epigastric pain and remained in the hospital 2 or 3 days and medication was administered by hypodermic for the pain. At this time he had no cough, sputum, or hemoptysis, but he had noted slight dyspnea on exertion ever since the stabbing occurred 2 years ago. He had to take paregoric occasionally for his nervous stomach. There had been a 20-pound weight loss over the 4-month period prior to admission. The remainder of his history was not related to the present illness.

The physical examination was essentially normal. He was a well developed, well-nourished white man appearing in good condition with no acute distress. The abdomen showed no mass or tenderness. The liver, spleen, and kidneys were not palpable. An admission chest film here showed a thin walled cyst or perhaps colon just above the left diaphragm anteriorly. The admission diagnosis was a possible traumatic diaphragmatic hernia with either bowel, stomach, or omentum in the hernia. Lung cyst and tumor were to be ruled out.

A diagnostic pneumoperitoneum was induced and appeared to show a solid organ below and above the left diaphragm apparently going through a hole in the diaphragm anteriorly. Fluoroscopy gave little additional information except for some restriction of motion of the left diaphragm and the finding of this solid density above the left diaphragm, approximately 8 cm. in diameter.

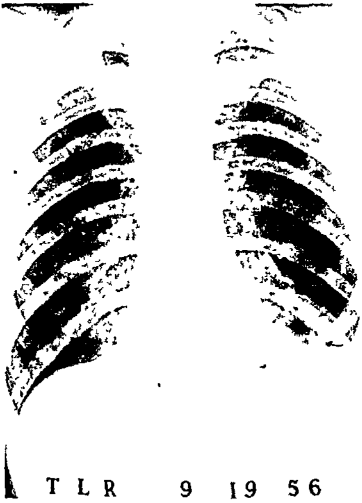

Fig. 5.

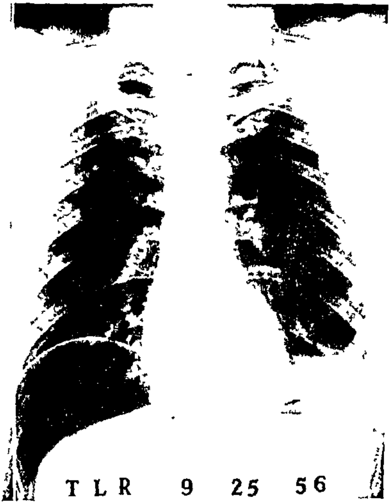

Fig. 6

Fig. 5.—Case 9, T. L. R. Sept 19, 1956 A PA chest film shows a poorly defined cystic shadow just above the left diaphragm medially This abnormality was missed in one or two other hospitals but on hindsight is fairly obvious.

Fig 6.—Case 9, T. L R Sept. 25, 1956. A diagnostic pneumoperitoneum has been induced There appear to be adhesions between the left diaphragm and subphrenic organs and the stomach shadow is somewhat unusual.

Intravenous pyelograms were normal. An upper gastrointestinal series was done and showed no stomach or colon above the diaphragm.

On Oct. 1, 1956, the left chest was explored through the eighth interspace and a traumatic diaphragmatic hernia discovered with a large mass of omentum above the diaphragm. This omentum was incarcerated and strangulated. There was a traumatic hernial opening anteriorly in the left leaf of the diaphragm about 3 cm. from its anterior insertion into the chest wall. The lung itself appeared normal. The hernial opening measured about 3 cm. in diameter. The omentum was everywhere adherent to the opening and was also adherent to the lower lobe of the lung in several places. These adhesions were ligated and divided. The hernial ring was freed of its adhesions and the omentum was then replaced in the abdomen. However, it was necessary to increase the opening [illegible] di [illegible] anot

2 cm. in order to reduce the herniated omentum. A two-layer closure was then made of the diaphragmatic opening, imbricating the two edges of the diaphragm, using interrupted mattress sutures of No. 1-0 cotton for the repair. The phrenic nerve was crushed lightly just above the diaphragm. The wound was closed in layers, with one intercostal tube for drainage.

The patient's recovery following surgery was uneventful and he was discharged on Oct. 11, 1956, to resume gradually his former activities.

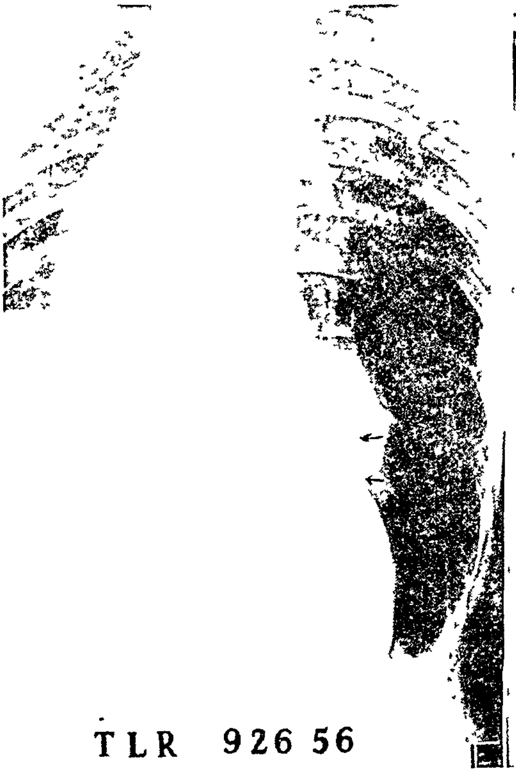

Fig. 7.

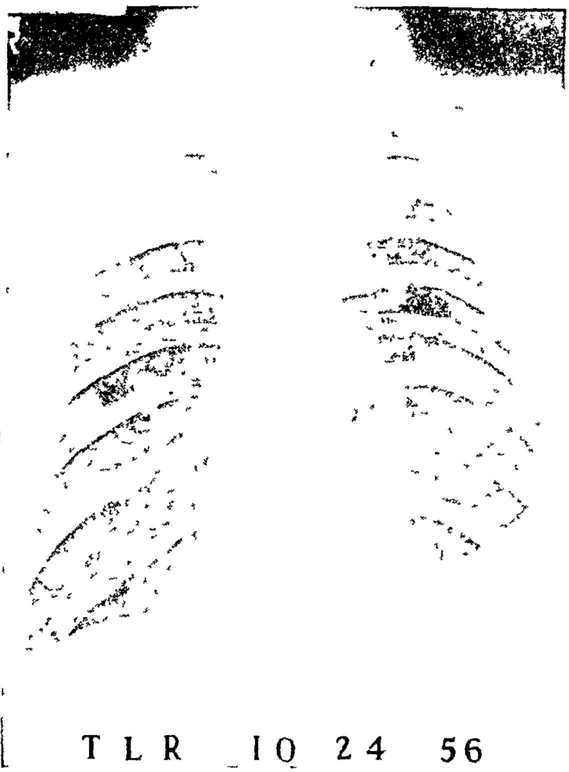

Fig. 8.

Fig. 7.—Case 9, T. L. R. Sept 26, 1956. This film was taken with the patient lying on his right side The pneumoperitoneum outlines a solid mass partially above and below the diaphragm which later was proved to be omentum going up through a rent in the diaphragm.

Fig. 8.—Case 9, T. L R. Oct 24, 1956 A postoperative film. There is slight pleural reaction on the left which is subsiding and the left diaphragm is slightly elevated due to the phrenic crush which was performed at the time of surgery in order to take stress off the suture line until it healed.

Case 10.—W. P. L., a 52-year-old white man, was admitted to the Baptist Memorial Hospital on April 19, 1951, on the service of Dr. R. L. Sanders and Dr. Turley Farrar. The patient stated that he had had a diaphragmatic hernia for sometime, but 24 hours before admission he had begun to have severe pain in the chest, mostly in the midline anteriorly. He had formerly had a diagnosis also of peptic ulcer. The pain did not radiate and was chiefly substernal in location. Five years before in Birmingham, Ala., a diaphragmatic hernia had been diagnosed. Over the 5-year period prior to admission here he had intermittent spells of vomiting, even on an ulcer diet.

Physical examination revealed a well-developed, well-nourished white man, not appearing acutely ill except for mild tachycardia. The blood pressure was 100/60 mm. Hg and the abdomen showed slight epigastric tenderness but no mass was palpated. The solid organs were not palpable.

Routine laboratory studies were essentially normal On April 20, 1951, Dr R L Sanders performed an exploratory operation on the patient's abdomen after first having Dr Farrar perform a left phrenic crush through a neck approach under Novocain anesthesia Fascia was removed from the left thigh and two sutures were prepared, only one of which was actually needed When the abdomen was opened it was discovered that about 60 per cent of the stomach was up in the chest and strangulated, with a very large opening in the diaphragm—large enough to admit the entire hand The stomach was dragged down out of the thorax and the peritoneum freed in front of the esophagus which was then liberated and mobilized Then the leaves of the diaphragm were elevated with Allis forceps and the opening of about 10 cm in the diaphragm was closed, using interrupted silk and then continuous fascial sutures This closed the opening fairly snugly around the esophagus, leaving enough room to admit two fingers beside the esophagus The stomach and duodenum were entirely negative with no evidence of peptic ulcer The patient's convalescence was uneventful following surgery and he was discharged on May 5, 1951

SUMMARY

Case reports are presented of 10 consecutive patients having strangulated diaphragmatic hernias observed in the John Gaston Hospital and Baptist Memorial Hospital, Memphis, Tenn, over a 10 year period Four of the 10 patients died following surgery, a mortality rate of 40 per cent in this small series

Strangulated diaphragmatic hernia is a serious surgical emergency with a relatively high mortality It is suggested that a more aggressive attitude be taken in treating this type of hernia before it becomes strangulated, as surgical repair of the hernia itself is simple with a very low mortality rate when no strangulation is present

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THE REPAIR OF THORACIC WALL DEFECTS WITH SLIDING RIB GRAFTS

An Experimental Study

Steven G. Economou, M.D., and Harry W. Southwick, M.D., Chicago, Ill.

THE most logical source of material to replace defects in the thoracic wall created during the course of major tumor surgery is the patient's own tissue. Available structures, however, have had the disadvantage of instability so that the surgeon is often tempted to add a foreign material to compensate for this.

Faced with a major chest wall defect at the close of a major surgical case, it is the rare instance where the surgeon finds the latissimus dorsi or pectoralis major muscles with their intact neurovascular supply available for repair. Fascia lata or the anterior sheath of the rectus abdominis muscle, tissues most commonly employed for such repair, can be used in most instances. The additional time consumed in obtaining them, or the necessity of having a second surgical team do this, has been their main disadvantage. Furthermore, these tissues do not offer ideal stability in many cases. This disadvantage is more of psychologic than physiologic importance. Closure of the defect simply with the overlying skin results in maximum paradoxical motion in this area. Although this does not significantly impair respiratory exchange, it is unsightly and disturbing to the patient. On occasion, necrosis of such overlying skin has resulted in near fatal pneumothorax.

A variety of heterologus prostheses have been used with the emergence of several basic conclusions. If it is to succeed, the heterologous prosthesis must not only be inert but must also offer both mobility as well as stability. Tantalum plates, used in the past, have been removed almost without exception because they became dislodged or became the focus of an infected sinus.[1, 2, 3] Although valuable in repairing defects that can be covered by muscle and full-thickness skin, tantalum mesh when used as a subcutaneous prosthesis becomes fragmented with slivers of wire protruding from the overlying skin and giving rise to chronic abscess formation.[4, 5, 6]

With this knowledge, the present authors conducted an experimental and clinical study of using sheets of Ivalon sponge as the prosthetic material.[7, 8] Because the vacuoles in this inert material intercommunicate freely, serum

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quickly permeated throughout to lay the framework for the fibroblasts and capillaries which followed. This resulted in a firm yet mobile support of inert substance permeated by living tissue. As in all instances where foreign substances are used, the contraindication to Ivalon being used in the presence of infection, or potential infection, significantly limited its use.

Our experience gave impetus to a further search for a prosthesis which presumably would be autogenous, easily available, offer stability, and yet be mobile. It was felt that a step toward such an achievement would be the development of a technique of providing sliding rib grafts. The ribs adjacent to a thoracic defect are readily available and easily mobilized in a short time and with their intact periosteum can serve as fresh autogenous grafts.

For the sake of greater technical ease, large mongrel dogs were selected for study. Surgery was performed under intravenous Nembutal anesthesia and endotracheal intubation. By removing a 4 cm. length of three consecutive ribs together with the intercostal muscles there was created a full-thickness defect of the right thoracic cage (Fig. 1).

The defect was now ready for repair. The intercostal muscles were separated from the superior (cephalad) aspect of the ribs which had been partially resected (Fig. 1, *A*). This was done lateral to the defect and for a distance sufficient to free an adequate length of rib which was to be mobilized. So that there would be a minimum of bleeding and in order that the neurovascular supply of the intercostal muscle would continue functioning, the muscle was deliberately sectioned at its insertion rather than at its origin. Care was taken not to remove the periosteum.

With a Stryker oscillating saw, using the narrow side of a fan-tail blade, the rib was split lengthwise as far laterally as the intercostal muscle had been freed (Fig. 1, *B*). With a short cross cut the appropriate length of rib was removed. A notch was made on the sectioned ribs medial to the defect so that they could receive the sliding graft. With a very small drill (preferably a dental drill) holes were made at the ends of the grafts and of the sectioned ribs on either side of the defect.

No. 32 stainless steel wire was passed through these holes and, with a figure-of-eight tie, the sliding grafts were secured in position. By trial and error the above ligature and tying techniques were found to be the most suitable to secure the graft and to prevent ligature fragmentation. After all the rib grafts were secured, the intercostal muscle was re-attached to the corresponding rib (Fig. 1, *C*). Because half the width of the rib was absent, the intercostal muscle had to be stretched somewhat in order to reach the rib below. Of course, over the site of the original chest wall defect, sliding rib grafts but no intercostal muscles were present. The overlying musculature and skin were then closed in layers.

At the conclusion of the surgery the rib grafts by their solid support prevented paradoxical motion of the thoracic wall, and yet were mobile in concert with the remaining ribs. In effect these were immediate autogenous rib grafts with intact periosteum. The majority (90 per cent) of the grafts survived and developed into viable solid supporting structures. In no instance did infection develop. The rib grafts that did not survive were absorbed. By the time this was evident, fibrous tissue had sufficiently infiltrated this area so that the defect could be detected only by x-ray. Occasionally there developed a pseudoarthrosis at the point where the sliding graft was anchored. This could be demonstrated by x-ray (Fig. 2) but was not detrimental.

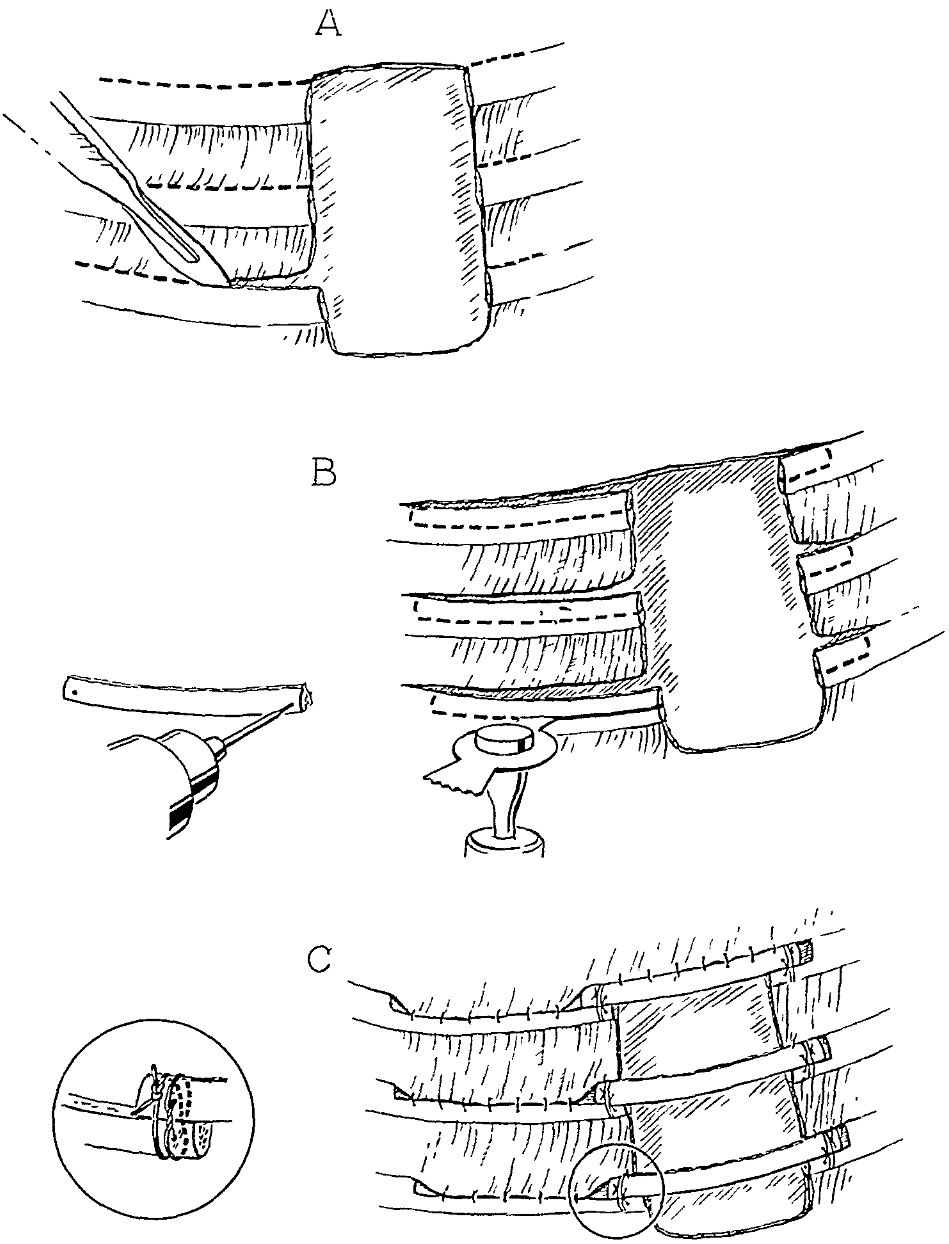

Fig. 1.—Composite drawing of operative technique of sliding rib grafts.

A, Intercostal muscle is divided at its insertion and sufficiently laterally to allow an appropriate length of rib to be mobilized.

B, The cephalad portion of the rib with its intact periosteum is split lengthwise with a Stryker oscillating saw. A short notch is made in the ribs medial to the defect. Holes are drilled at all the rib ends.

C, The grafts are anchored in place with figure-of-eight ties, using No. 32 stainless steel wire (see insert). The intercostal muscles are then re-attached to the corresponding ribs.

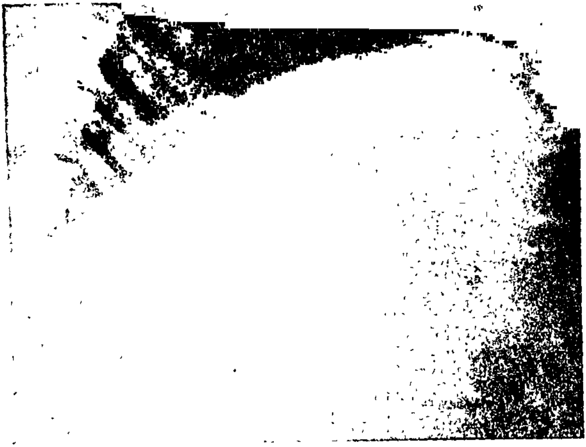

Fig. 2.—Lateral chest x-ray in a dog having sliding rib grafts performed 20 weeks previously. One graft did not "take" and pseudoarthrosis is present in two other areas. Neither of these deficiencies resulted in functional impairment.

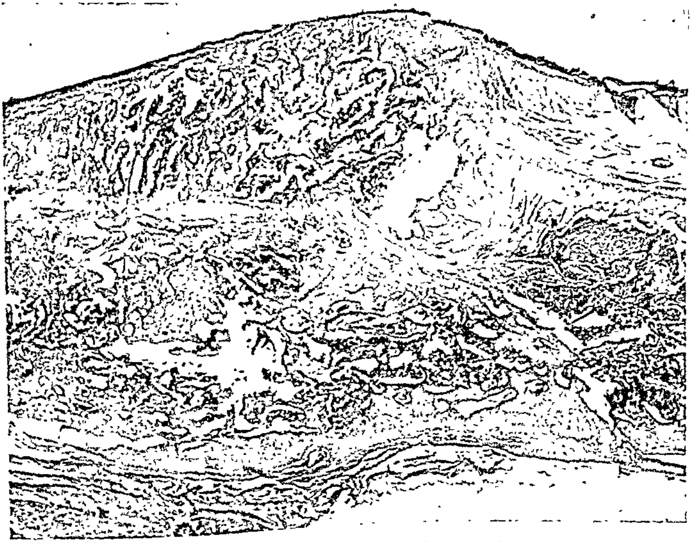

Fig. 3.—This is a photomicrograph of a sliding rib graft junction at the end of 20 weeks. In the upper right portion of the picture is the sliding rib graft. It is indistinguishable from the ribs (left lower portion of picture) to which it has been anchored.

The procedure was performed on 15 animals; some on both sides. The animals were sacrificed at intervals of 2 to 50 weeks. At autopsy, there were variable lung adhesions to the surgical site but most of the area was covered with parietal pleura. The grafted region was as firm if not more so than the adjacent tissues. On microscopic examination the grafted ribs are indistinguishable from those on the recipient site (Fig. 3).

SUMMARY

In the process of excising chest wall tumors, or when, because of locally invasive bronchogenic carcinoma, a portion of the chest wall has to be sacrificed along with the lung, there is the necessity of adequately repairing the resultant defect. To meet this problem we have developed in dogs a technique of immediate autogenous sliding rib grafts. The high incidence of success in animals justifies clinical application.

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THE ARTERIAL DISTRIBUTION TO THE RIGHT UPPER PULMONARY LOBE

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We have previously reported[1] on the arterial distribution to the left upper lobe, a subject on which there has been considerable misinformation in the literature. While collecting data for the above report we have used the same type data sheets to accumulate information on the arterial distribution to the right upper lobe. Although the arterial supply to the latter is considerably more constant, we have encountered 13 variations in 200 cases. It is felt that a set of simple "maps" may be useful to residents in training and to the occasional operator.

METHOD OF STUDY

Each right upper lobectomy or segmental resection of the right upper lobe performed at Herman Kiefer Hospital was charted immediately after surgery as to the distribution of the arteries. As a teaching procedure for the resident staff, each arterial stem was traced to its first major branching and the destination of these branches determined. Those segmental operations were excluded in which calcification and scarring would have rendered hazardous dissection of vessels other than those which required ligation for the proposed operation. No attempt was made to subdivide the individual pulmonary segments or the arteries thereto. While the identification of the secondary and tertiary branches of the segmental arteries is a delight to the anatomist, it has relatively little surgical importance. The present report is based on 200 cases where the entire arterial supply to the right upper lobe could be clearly identified and traced.

RESULTS OF THE STUDY

From Table I it is evident that in nearly three quarters of cases the right upper lobe is supplied by two arterial trunks.

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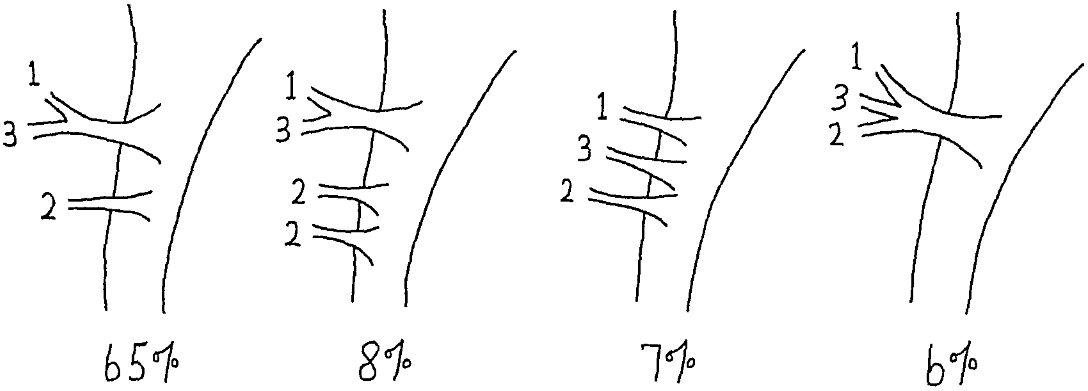

Fig. 1.—The most common arterial distributions to the right upper lobe. These four patterns account for 86 per cent of all cases. In all figures, the Jackson-Huber classification is used with *1* representing the apical, *2* the posterior, and *3* the anterior segmental arteries.

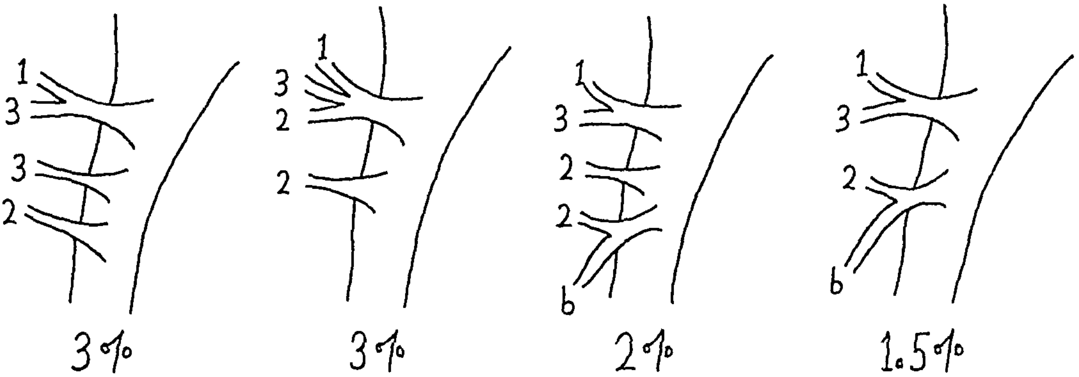

Fig. 2.—Less common distributions. Note the 3.5 per cent of cases in which supply to the posterior segment is derived from the artery to the superior division of the lower lobe.

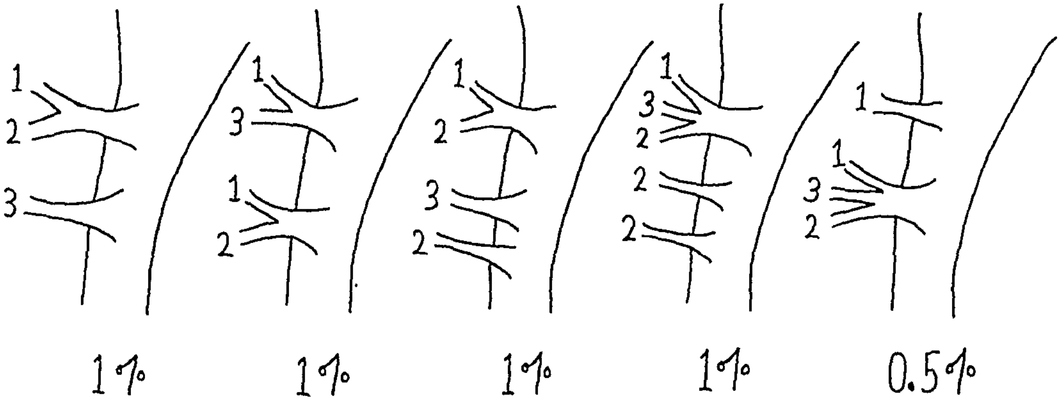

Fig. 3.—Least common distributions. These five variations are found in only 4.5 per cent of cases.

TABLE I. NUMBER OF ARTERIAL TRUNKS TO THE RIGHT UPPER LOBE

NUMBER OF BRANCHES	PER CENT OF CASES
1	6
2	72
3	22
Total	100
Mean 2.2	

The illustrations are more or less self-explanatory. In Fig. 1, it is seen that 65 per cent of all cases have an apico-anterior and a posterior trunk. In another 8 per cent, there are two posterior trunks. The four distributions shown in Fig. 1 account for 86 per cent of all cases. Fig. 2 reveals that, in 3.5 per cent of cases, all or part of the arterial supply to the posterior segment will be derived from the artery to the superior segment of the lower lobe. In the 7 cases in which this occurred, the branching was so proximal that it was immediately recognized and the supply to the superior division was saved in all instances. Fig. 3 shows the least common form of distribution, occurring in less than 5 per cent of cases.

Table II shows the number of individual branches supplying each segment. It will be noted that, in the great majority of cases, each segment is supplied by only one artery.

TABLE II. NUMBER OF INDIVIDUAL BRANCHES TO EACH SEGMENT

	SEGMENT 1	SEGMENT 2	SEGMENT 3
One artery	98.5	85	97
Two arteries	1.5	14	3
Three arteries	0.0	1	0
	100%	100%	100%

CONCLUSIONS AND SUMMARY

Two hundred cases are presented in which the arterial distribution to the right upper lobe has been accurately mapped. No startling anomalies have been encountered. Three quarters of all cases are supplied by an apico-anterior and either one or two posterior trunks. In the remaining quarter of the cases, eleven additional distributions have been identified. In the latter cases perhaps the most significant are the 3.5 per cent where the posterior segment is supplied from the artery to the superior division of the lower lobe.

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EVENTRATION OF THE DIAPHRAGM: HERNIATION OF THE LIVER INTO THE LEFT AND RIGHT HEMITHORAX

A Case Report

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THIS is a report of a case of eventration of the diaphragm occurring in a 5½-year-old boy. The only abdominal organ extending into the chest was the liver, which was found in the right as well as the left chest.

There is extensive reporting on the subject of eventration of the diaphragm with herniation of the liver into the chest, otherwise known as partial eventration of right diaphragm, superior accessory lobe of liver,[1] or hernia diaphragmatica dextra hepatica.[2] Several excellent reviews of the literature on this subject have appeared recently.[3-6] The majority of reported cases have been those of right-sided herniation. A careful review of the literature reveals no previously reported cases of bilateral eventration of the diaphragm. We would like to report such a case in detail, one which simulated an intrathoracic tumor.

CASE REPORT

D. H., a 5½-year-old boy, was referred from Anchorage, Alaska, with the chief complaint of deformity of chest, poor growth, and a "mass in the chest." The child was born prematurely, weighing 2.64 kilograms (3 pounds 10 ounces), following a normal pregnancy and delivery. Both the father (39 years old) and the mother (42 years old) were in good health. Family history revealed a half sister, 19 years old, who had had a neurofibroma about the size of a walnut removed from the mediastinum. Her recovery was uncomplicated.

The first 5 years of life were uneventful except for the occurrence of whooping cough at the age of 4 months. The first chest film was made approximately 8 months before admission here because of a prominence of the cartilages over the left chest, and revealed a mass within the chest confluent with the cardiac shadow. The child was completely asymptomatic as far as the heart and lungs were concerned.

Physical examination at the time of admission revealed a very slender, asthenic boy who appeared quite lively and sociable, although his over-all performance gave one the impression of mild retardation. He weighed 13.62 kilograms (30 pounds) and was 82 cm. tall. His head circumference was 46 cm., which is in the 50 percentile for a 9-month-old child.

The positive physical findings other than his small size were limited to the chest. There was a mild, left precordial bulge with prominent junctions of the cartilages and ribs. No abnormal heaves or thrills were noted. Careful percussion revealed an increased

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area of dullness in the lower mediastinum. The breath sounds were of good quality throughout. The heart rhythm was regular, the rate was not remarkable, the heart sounds were of good quality and the second sound was single and of normal intensity. A Grade 2 systolic murmur was best heard at the apex; this changed with position and had the quality of a functional murmur. The pulses were of good quality throughout. The blood pressure was 112/75 mm. Hg.

Laboratory work revealed a hemoglobin of 12.3 Gm., packed cell volume 40, white cell count 10,150, normal differential; urine clear; tuberculin 1:1000 negative, Schick negative; Echinococcus skin test, negative. A psychometric examination revealed his mental age to be 4 years 4 months, with a borderline classification of intelligence.

An electrocardiogram showed a notched, slurred S in Lead V_1 which could indicate an impaired right conduction but also could well be within normal limits.

Roentgenograms of the chest revealed a large homogeneous mass in the lower anterior portion of the thorax which was contiguous with the contour of the anteromedian segment of both the right and left hemidiaphragm as well as the base of the cardiac silhouette (Fig. 1).

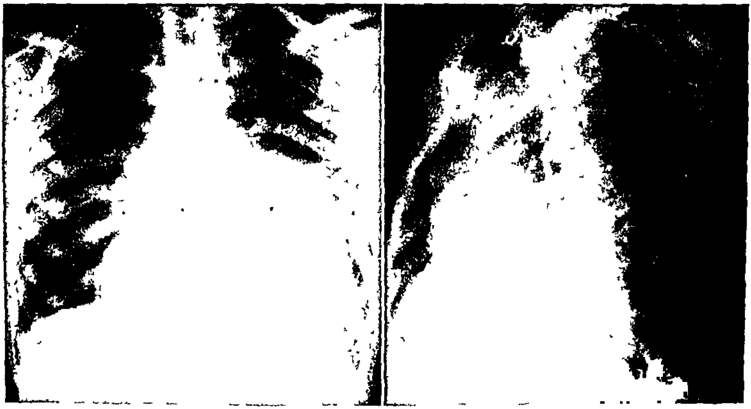
A. B.

Fig. 1.—*A*, Roentgenogram of chest in the posteroanterior projection. Note large homogeneous mass contiguous with the base of the cardiac silhouette which is rotated and displaced cephalad.

B, Left anterior oblique projection of chest demonstrating contiguity of the mass to the cardiac shadow and both leaves of the diaphragm.

Fluoroscopic examination of the chest disclosed no abnormality of the diaphragmatic excursion. The mass which moved synchronously with both leaves of the diaphragm exhibited no alteration in size or shape with respiration and no intrinsic pulsation was detected. An angiocardiogram revealed no intrinsic abnormality of the cardiac chambers or of their sequence of opacification. The cardiac silhouette, however, was compressed and displaced cephalad and slightly posterior by the large mass, in which no contrast material was detected (Fig. 2). Although the study did not conclusively establish the location of the mass, a tentative diagnosis of a mediastinal tumor—most probably a pericardial cyst—was made.

A bilateral exploratory thoracotomy and a limited laparotomy were performed on March 29, 1957 (H. B. S.). A transverse incision was made, centered over the fourth interspace, and carried from one anterior axillary line to the other and across the sternum. Both pleural cavities were entered. Later, in order to more clearly the inferior segment of the sternum was divided in the midline and a "T" extension of the incision carried through the anterior abdominal wall into the peritoneal cavity. This latter incision extended downward almost to the umbilicus.

A thorough exploration of the chest was performed, as well as a limited exploration of the peritoneal cavity. The findings appeared to be a failure of development of the tendinous portion of both hemidiaphragms. The defective development involved the central tendon of the diaphragm only. The muscular portion appeared entirely normal. Both the pleural and the peritoneal cavities were intact.

The liver protruded through this central portion of the diaphragm and presented itself in the chest just posterior to the lower segment of the sternum. It was located in the midline just beneath the heart and had a bilobular appearance, as illustrated in Fig. 3. The left lobe of the liver was abnormally enlarged. The round ligament seemed to be in the normal location and the right lobe of the liver was thought to be of normal size. No attempt was made to determine the location of the gall bladder. A biopsy was taken from the left lobe of the liver and revealed entirely normal liver tissue. It was not thought possible to repair the very large defect which involved the central portion of the diaphragm and the abdominal and chest incisions were closed. The child had an uneventful hospital course and was discharged on the twelfth postoperative day.

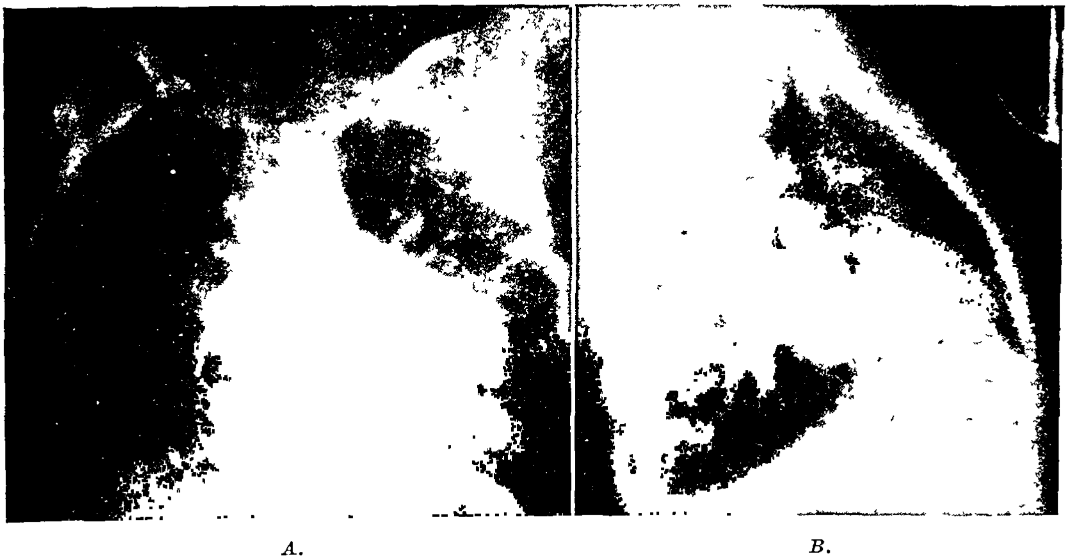
A. *B.*

Fig 2.—*A* and *B*, Angiocardiogram in anteroposterior and left lateral projection showing displacement and rotation of heart by nonopacified mass.

DISCUSSION

The roentgenographic findings associated with partial eventration of the right leaf of the diaphragm with herniation of the liver are usually sufficiently characteristic[3-5] so that the diagnosis can be reached with ease. However, in this case, the location of the mass in the chest immediately inferior to the heart and centrally in the chest was misleading. To our knowledge, eventration of the diaphragm in this particular location has not been reported previously. The angiocardiogram was performed to further ascertain the relation of the anteromedian mass to the heart and to the diaphragm. This clearly revealed that the mass was extracardiac, but did not clarify its position with respect to the diaphragm.

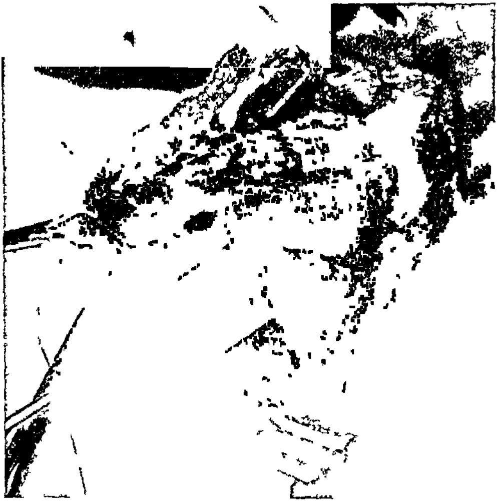

Fig 3A —Surgical Exposure The patient is in the supine position The head is to right and the feet are to left

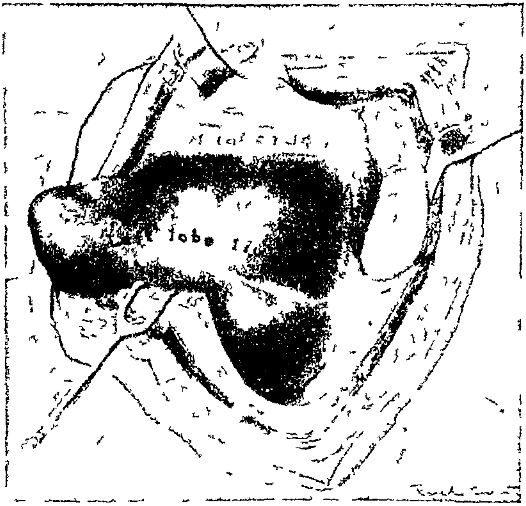

Fig 3B —Note protrusion of enlarged left lobe of liver into the central portion of the thorax

In retrospect it is apparent that a diagnostic pneumoperitoneum would have been the roentgenographic procedure of choice and would have led to the proper diagnosis preoperatively.[7] This is illustrated by Fig. 4 which depicts another case in which there was a partial eventration of the left leaf of the diaphragm with herniation of an abdominal viscus.

The more commonly described cases of eventration of the right diaphragm and herniation of the liver into the right chest are due embryologically to a failure of formation of the muscular portion of the diaphragm.[3, 4] In the case reported here, the developmental failure responsible for the eventration was failure of formation of the central tendon which derives from the central portion of the septum transversum. The muscular part of the diaphragm appeared normal but, instead of a strong firm central tendon, only the thin pleural and peritoneal layers were present.

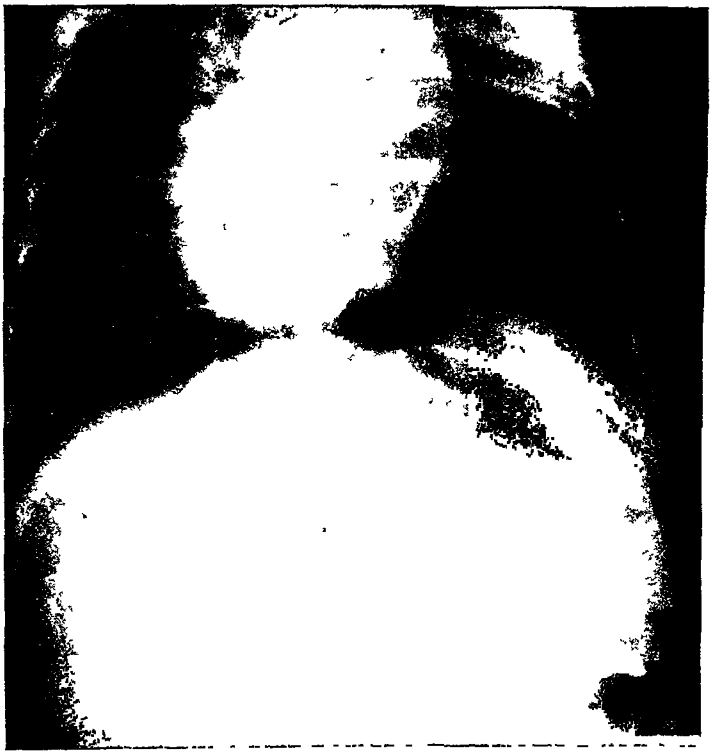

Fig. 4.—Film of abdomen following diagnostic pneumoperitoneum demonstrating intact diaphragm

This, therefore, represented a congenital malformation with nondevelopment of the central tendons of the diaphragm. The physiologic intra-abdominal pressure stretched the very thin membranous central portion of the diaphragm, enabling a portion of the liver—involving both lobes—to prolapse into the diaphragmatic pouch thus developed.

The importance of recognizing eventration of the diaphragm with herniation of the liver preoperatively has been stressed previously.[4, 7, 8] In our case, we were misled by the fact that the eventration occurred in the area of the central tendon of the diaphragm instead of the mucular portion of the right or left side. This case is being reported to call attention to the possibility of this diagnosis in those cases where the suspected intrathoracic mass is located centrally.

SUMMARY

This is the report of a case of eventration of the diaphragm with herniation of the right and left lobes of the liver into both sides of the chest, due to failure of proper formation of the central portion of the central tendon of the diaphragm.

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WELLES, EDWARD S. .... 20 Church Street, Saranac Lake, N. Y.

Members Deceased

RUDOLPH MATAS
FRANK I. TERRILL
GABRIEL TUCKER

ANNUAL MEETING NOTES

The Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery was held in Boston, Massachusetts, May 16, 17, and 18, 1958. There were 1,157 physicians who registered for the scientific sessions. In addition there were 142 wives present.

The first day of this year's meeting was dedicated to the memory of Evarts A. Graham. It is planned that the papers read on this day will comprise a special issue of THE JOURNAL OF THORACIC SURGERY and be appropriately marked. To further perpetuate his memory the Traveling Fellowship of this Association has been renamed The Evarts A. Graham Memorial Traveling Fellowship. Mrs. Graham was an honored guest of the Association during this meeting.

The headquarters office of the Association has proved itself over the two-year period that it has been in operation. It, therefore, becomes evident that the Association should no longer continue to impose upon the generosity of Washington University for this space. To this end the necessary funds were appropriated with which to set up an administrative office in the St. Louis area. The new address of this office will be Carondelet Building, 7730 Carondelet Avenue, St. Louis 5, Missouri.

The problems posed by the unprecedented growth of the Association and the report of the special committee that has studied them for two years were discussed at great length in Executive Session. However, no clearly acceptable method for strictly limiting the membership was evolved. The size of the attendance at our annual meetings is undergoing further scrutiny.

The following changes in membership status were voted by the Association during its Executive Session:

Seven members were dropped from the rolls of the Association either through the acceptance of their resignations or because of nonattendance.

The following Active members were elevated to Senior status:

Andre Cournand
John H. Garlock
Harlon W. Harrison
Harold A. Kipp
Charles W. Lester
Alton Ochsner
Forrester Raine
Arthur S. W. Touroff

The following Associate members were elevated to Active membership:

Richard H. Adler
Neil C. Andrews
John W. Bell
Ralph Berg, Jr.
Jacques Bruneau
Robert Fox
Sanford W. French III
Frank Glenn
Alfred Goldman
Joffre-Andre Gravel
James D. Hardy
Ormand C. Julian
Winfield O. Kelley
C. Frederick Kittle
Harvey J. Mendelsohn
Bertrand W. Meyer
Andrew G. Morrow
Paul Nemir, Jr.
Melvin M. Newman
Francis J. Phillips
Benson B. Roe
John M. Salyer
Hawley H. Seiler
John Y. Templeton III
Gordon W. Thomas
Harry E. Walkup
Elton Watkins, Jr.

The following candidates were elected to Associate membership:

Jay L. Ankeney, Cleveland, Ohio
Raymond J. Barrett, Detroit, Mich.
Charles A. Beskin, Baton Rouge, La.
William S. Blakemore, Philadelphia, Pa.
Ivan W. Brown, Jr., Durham, N. C.
John C. Callaghan, Edmonton, Alberta, Canada
Gilbert S. Campbell, Minneapolis, Minn.
Francis H. Cole, Memphis, Tenn.
E. Stanley Crawford, Houston, Texas
Julio C. Davila, Philadelphia, Pa.
Gerard Desforges, Melrose, Mass.
Thomas B. Ferguson, St. Louis, Mo.
Charles W. Findlay, Jr., New York, N. Y.
Joseph M. Ford, New York, N. Y.
Raleigh M. Hood, San Leandro, Calif.
Charles A. Hufnagel, Washington, D. C.
Karl E. Karlson, Brooklyn, N. Y.
Harvey W. Kausel, Albany, N. Y.
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James Alastair Key, Toronto, Ontario, Canada
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Arthur C. Miller, Loma Linda, Calif.
Joseph D. Morris, Ann Arbor, Mich.
Thomas F. Nealon, Wynnewood, Pa.
Adrian J. Neerken, Kalamazoo, Mich.
Russell M. Nelson, Salt Lake City, Utah
Rush E. Netterville, Jackson, Miss.
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Morris Rubin, Bronx, N. Y.
David C. Sabiston, Baltimore, Md.
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Frank C. Spencer, Baltimore, Md.
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Mark W. Wolcott, Coral Gables, Fla.

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Original Communications

ON THE PATHOGENESIS OF CARDIOSPASM

An Experimental Study

P. Alnor, Dr.Med., Kiel, Germany

INTRODUCTION

CERTAIN swallowing difficulties were described by Willis (1672) and later by Hoffmann (1733) and Purton (1821). In 1881, von Mikulicz gave the syndrome the name of "cardiospasm." Although it is now generally recognized that the condition is not associated with any true spasm, this name is still widely used. During the last few decades, numerous cases have been described, but the etiology and pathogenesis are not yet properly understood. In addition, it was not until recent years that general therapeutic principles began to emerge from the critical analyses and comparisons of the late results achieved by different types of treatment.

Although the condition is still commonly referred to as cardiospasm, the name achalasia, i.e., failure of the cardiac orifice to open after all the reflex movements of deglutition have come to an end, is far more correct and should be preferred. The clinical picture described by von Mikulicz is not associated with any spastic condition of the esophagus. Diffuse spasm of the esophagus is a separate clinical entity (Olsen and associates) and should not be confused with achalasia, although both conditions may be seen in association with one another. Spasm of the esophagus is accompanied by hypermotility, achalasia by hypomotility or even paralysis of the entire esophagus (Pupple). The contractions are often irregular, incoordinated and, as a rule, refractory to

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From the Chirurgische Universitatsklinik, Kiel, Germany; Head Professor, Dr R. Wanke.
Received for publication March 10, 1958.

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cold; he observed that administration of antihistamine decreased both the intensity and the duration of the vasoconstriction Judging by this investigation, it must be assumed that the decrease in the circulation persisting for some time after the application of the cold must enhance the immediate effect of the actual injury According to Bottcher, nervous tissue is still more vulnerable to cold than the musculature and, apart from bone marrow, it is the tissue most sensitive to cold Injury producing severe damage to the muscle tissue is thus also capable of injuring nervous tissue It appears probable that the vasoconstriction produced by histamine will involve not only the vessels in the actual region exposed to the cold but also in the surroundings In such an anoxemic region the protracted lack of oxygen supply may injure the nervous tissue there more than the somewhat less sensitive muscle tissue

In an attempt to injure Auerbach's plexus, the cardia was exposed to local cold The experiments were carried out on rabbits and dogs

EXPERIMENTAL DATA

Carbon dioxide snow was applied locally to the region of the cardia via a specially constructed copper tube arrangement, a modification of the apparatus described by Speransky In this way about 1 cm of the cardiac region was exposed to a temperature of about -80° for half a minute.

The animals were anesthetized with morphine-atropine + Somnifen intravenously. Via an upper median incision, the stomach was exteriorized and the cardia made accessible The surroundings of the cardia were draped and the copper tube placed around the esophagus and connected to a carbon dioxide cylinder for half a minute The frozen region first turned white, but after a few minutes it became pink The drapes were then removed and the abdomen was closed Twenty-four hours later, when the effect of the anesthetic had worn off, the animals ran about in their cages as usual, and 2 days later they were eating as usual. The immediate postoperative course was never complicated

During the subsequent 7 to 9 months the animals also appeared to feel well In one group of 12 dogs, 4 showed a distinct, 3 a slight loss in weight; 4 had the same weight, and 1 had gained a little in weight Swallowing difficulties, although relatively slight, occurred during the last months only in 2 animals; in three others there was occasional vomiting of undigested food during the experimental term Some of the rabbits lost considerable weight toward the end of the experimental period Most of them had, however, been killed earlier (one group per month) in order to study the progress of the changes in the region of the cardia

Roentgen Findings—The esophageal lumen in dogs, which is usually about the thickness of an ordinary lead pencil (Fig 1, *A*), and through which food usually passes rapidly, was regularly dilated half a year after local freezing of the cardia, sometimes the dilatation was marked (megaesophagus), the wall was atonic and the passage of the food delayed No organic stenosis was seen in the region of the cardia (Fig 1, *B* and *C*).

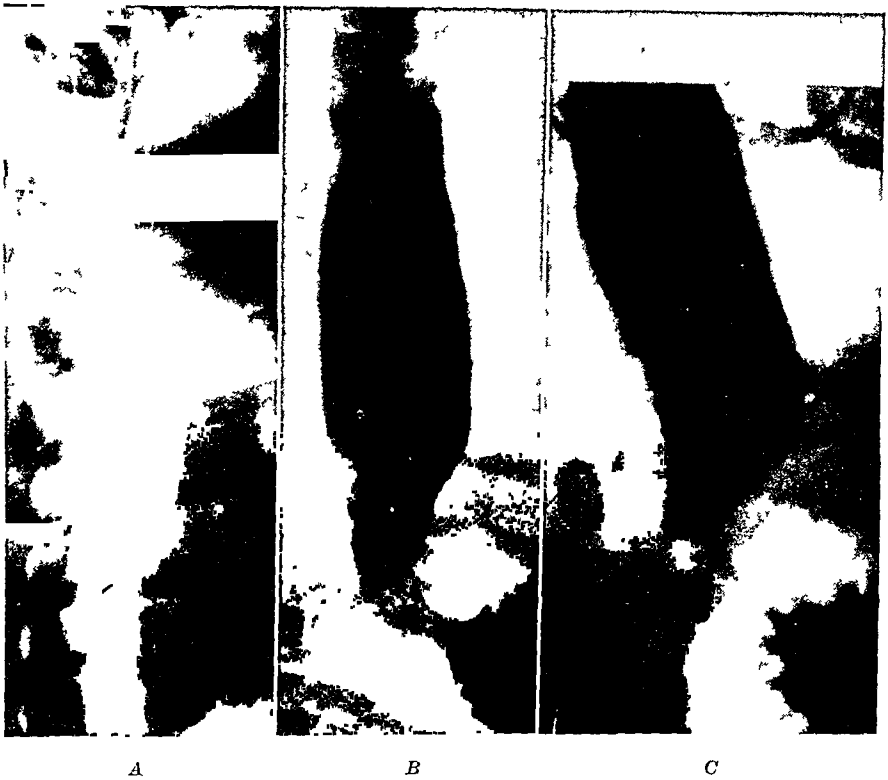

Fig. 1 —*A*, Normal esophagus (dog) *B*, Megaesophagus 7 months after cold injury (Dog 6) *C*, Megaesophagus 9 months after cold injury (Dog 1)

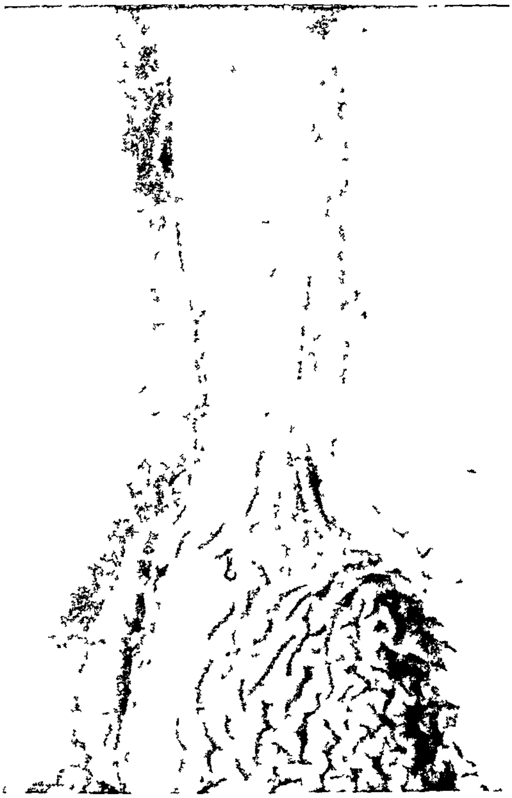

Fig 2 —Pronounced muscle hypertrophy (compensation stage) in Dog 4

Post-Mortem Examination.—Seven to 9 months after the experiment the animals were killed and the esophagus and stomach immediately removed and fixed in formalin.

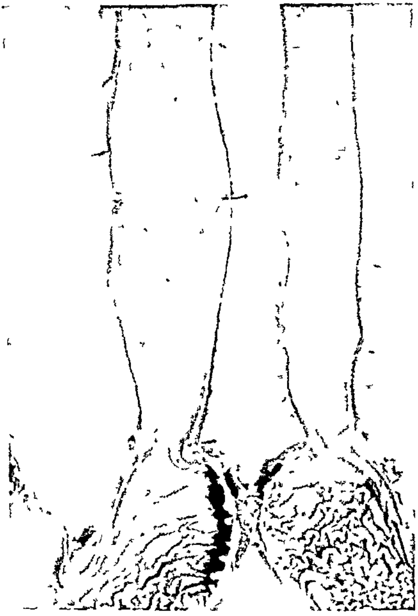

Fig 3

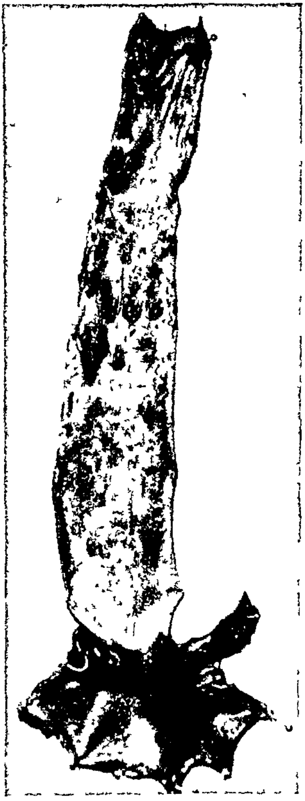

Fig 4

Fig 3 —Distinct esophageal dilatation (commencing decompensation) in Dog 3

Fig 4 —Rabbit esophagus 12 weeks after cold injury Note pronounced dilatation of esophagus and inflammatory changes of the mucosa because of commencing stercoral esophagitis with numerous superficial erosions and ulceration The widening of the actual cardia is almost negligible

The longitudinal cut surface of the esophagus showed pronounced muscular hypertrophy, especially in the lower third (Fig. 2) In such preparations, the dilatation was also more distinct than in unslit specimens (Figs 3 and 4).

As a rule, the caliber of the esophagus had increased two- to threefold, but the cardia never showed any cicatricial stenosis after the injury by the cold.

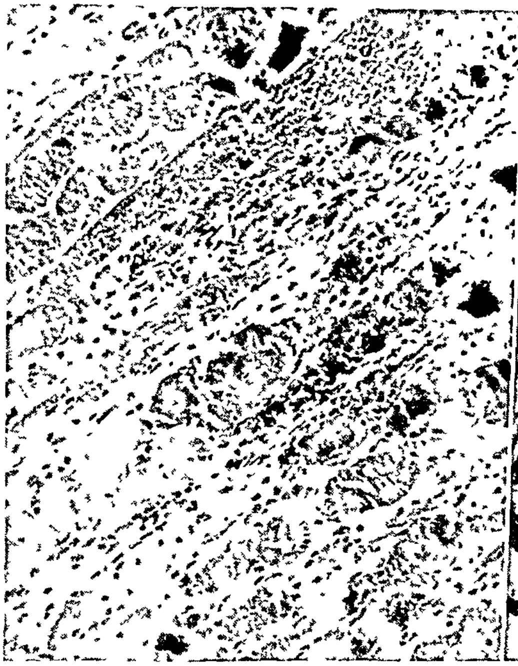

Fig. 5

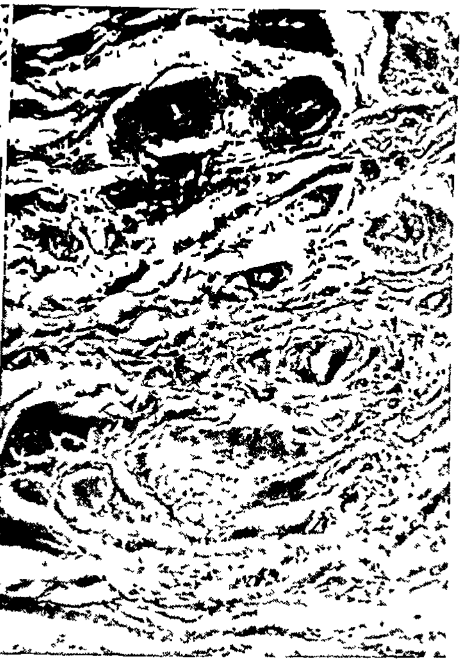

Fig. 6

Fig. 5.—Necrosis of the musculature of the cardia of a rabbit 48 hours after exposure to extreme cold. The muscle fibers are broken up (coagulation necrosis). Edema between the muscle fibers with swollen fibrocytes and invading histiocytes. (Hematoxylin and eosin, ×160, reduced ¼.)

Fig. 6.—Result of cold injury. Wavy (Zenker's) degeneration of the muscle fibers, loss of parenchyma and dissociation. (Hematoxylin and eosin, ×120, reduced ¼.)

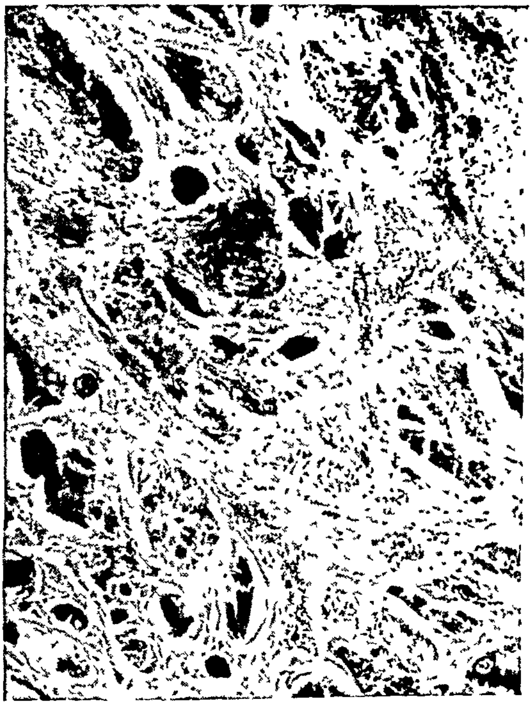

Fig. 7.—Tissue excised from human cardia with achalasia for comparison with Fig. 6. Severe loss of musculature with pronounced collagenous connective tissue between the dissociated and degenerated muscle fibers. Diffuse and focal round cell infiltration.

The cardia was closed in the usual way after death, and the mucosa was intact. The dilatation above the cardia was thus not due to organic stenosis but to a functional disturbance, i.e., the failure of the cardia to relax.

Histologic Findings.—In all of the animals, the cardia showed typical changes due to local freezing. The changes were more pronounced in the rabbits than in the dogs (Fig. 5).

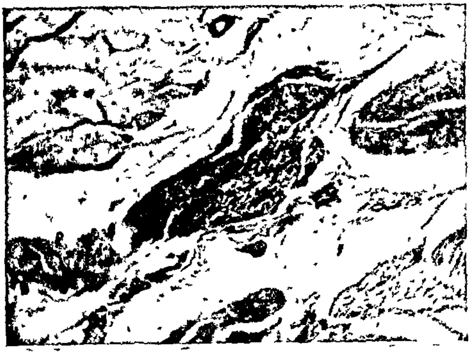

Fig. 8.

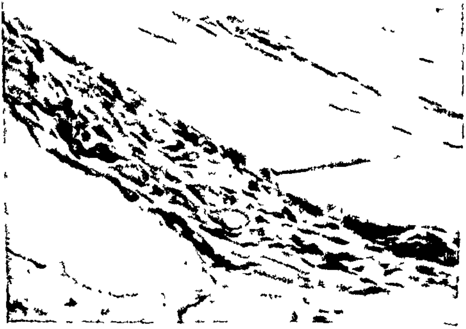

Fig. 9.

Fig. 8.—Ganglion of Auerbach's plexus of the cardia. Marked increase in supporting [illegible] and connective tissue. The number of ganglion cells is decreased, although the total pl[illegible] larger than normal. (Nissl's method, ×120; reduced ¼.)

Fig. 9.—Autonomic parasympathetic ganglion of the cardia with numerous deg[illegible] ganglion cells. Vacuolation of the plasma, missing nuclei (confirmed in serial sectio[illegible] creased number of capsule and supporting cells. (Nissl's method, ×200; reduced ¼.)

Fig. 6 shows a typical picture 9 months after injury by cold. Th[illegible] is limited to a region about 1 cm. wide (width of the copper tube c[illegible] the carbon dioxide snow) and showed the same histologic picture as [illegible] in excised tissue from the cardia of human beings with achalas[illegible] namely, cardiac sclerosis.

The tissue above the frozen region showed marked [illegible] musculature, but the mural layers were otherwise of [illegible]

Fig 10

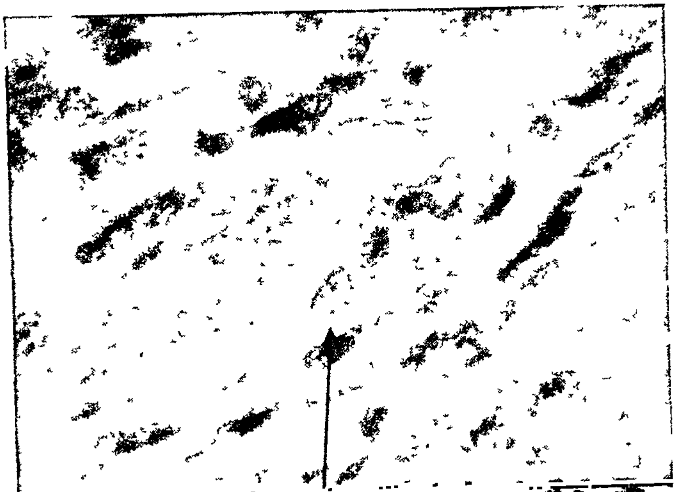

Fig 11.

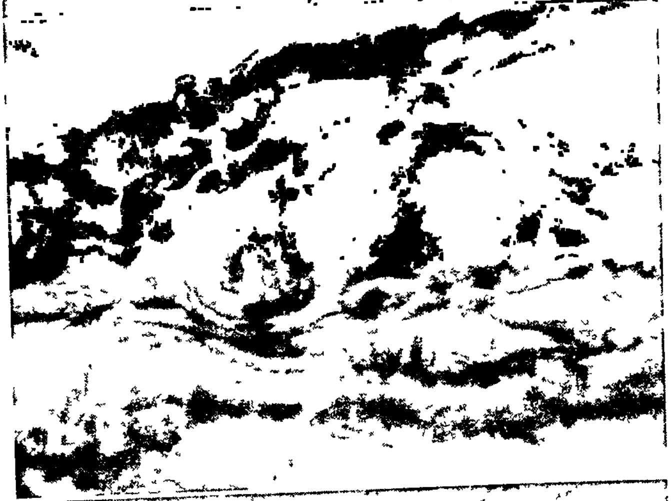

Fig. 12

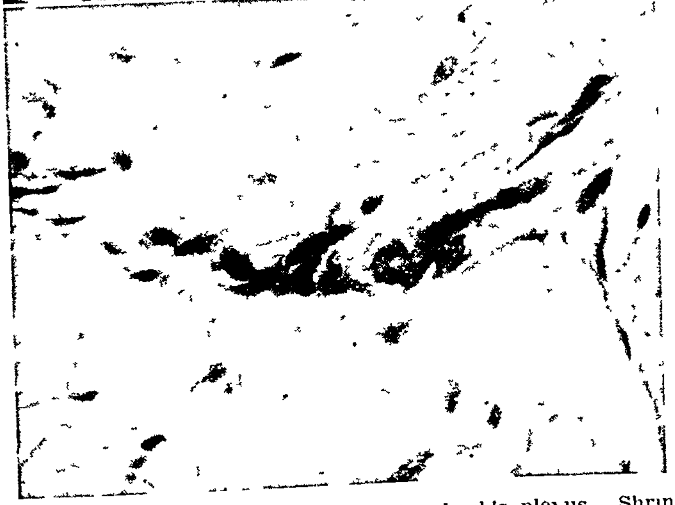

Fig 10.—Initial change of a ganglion cell of Auerbach's plexus Shrinkage of the cell, intracellular vacuolation, clumping of the tigroid, and the marginal position of the nucleus indicate degeneration Arrow indicates a phagocytosing capsule cell (Nissl's method, ×600, reduced ¼)

Fig. 11.—Advanced changes of a ganglion cell of Auerbach's plexus Pronounced shrinkage of the cell with retraction from the capsule and numerous small and large vacuoles in the cytoplasm. Complete destruction of the nucleus Neuronophagia

Fig 12.—Growth of intercalary cells in the musculature of the esophagus 9 months after cold injury.

the other hand, between the annular and longitudinal musculature in the region of Auerbach's plexus there was a striking accumulation of round cells distinctly demarcating this otherwise hardly discernible region (Figs 8 and 9)

Under high magnification it was seen that some of the ganglion cells had been completely or partly replaced by proliferating capsule and interstitial cells and some showed considerable degenerative changes (Fig 10). Here various degrees of degeneration of the ganglion cells were observed with commencing neuronophagia The ganglion cells were swollen, the Nissl bodies were clumped or dissolved, the ganglion cell nucleus was seen near the margin of the cell and in the periphery of the cell phagocyting supporting cell elements (Fig 11).

The above-mentioned ganglion cell changes corresponded to those described by Etzel in 2 cases of early achalasia and the entire picture of the changes in Auerbach's plexus and in the surroundings was the same as that reported in the 4 early cases

In our animal experiments, the cases may be regarded as early because all the animals were studied within 9 months of the freezing of the cardia with release of histamine and consequent lack of oxygen supply to Auerbach's plexus But, even after such a short period, the further course of the injury was readily recognized (Fig 12) The intercalary cells in the cardiac muscle coats were hyperplastic According to Feyrter, such hyperplasia is a typical expression of the response of the vegetative nervous system to chronic irritation with an accumulation of sustentacular cells in the wall.

Further progress of the changes described above will, of course, lead to a final stage which Wanke found in a clinical series of achalasia and which he called sclerosis cardiae

DISCUSSION

The observations made in the present investigation thus showed that by freezing the cardia in the rabbit and the dog it is possible to produce the clinical picture of achalasia with muscular hypertrophy of the esophageal wall and secondary dilatation of the esophagus oral to the cardia Roentgenography never showed cicatricial stenosis, and the mucosa was always intact Histologically the frozen region resembled the end stage of achalasia described by Wanke as cardiac sclerosis (Figs 13 and 14) Oral to the frozen region, Auerbach's plexus showed striking changes and corresponded in all respects to that described by Cameron, Cross, and Etzel in cases of early achalasia From this region the disease proceeded via the intercalary cells in the musculature of the cardia and finally resulted in complete structural degeneration—cardiac sclerosis.

According to the present experiments, the first stage in the development of achalasia is an impairment of the circulation with consequent destruction of the neural elements of the cardia This circulatory disturbance is due to the fact that the histamine released in the cardia region exposed to the cold results in protracted vasoconstriction not only of the actually chilled region

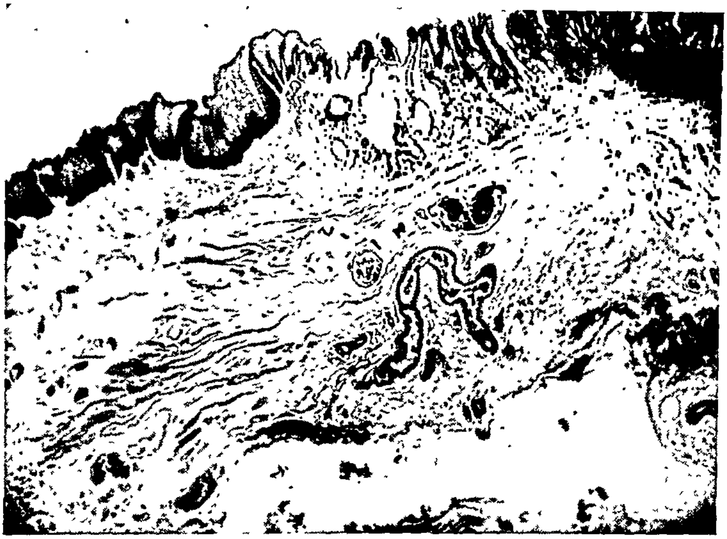

Fig. 13.—Pronounced cardiac sclerosis of a dog 9 months after cold injury. The normal wall layers have been substituted by fibrous connective tissue; only small rests of the musculature are visible.

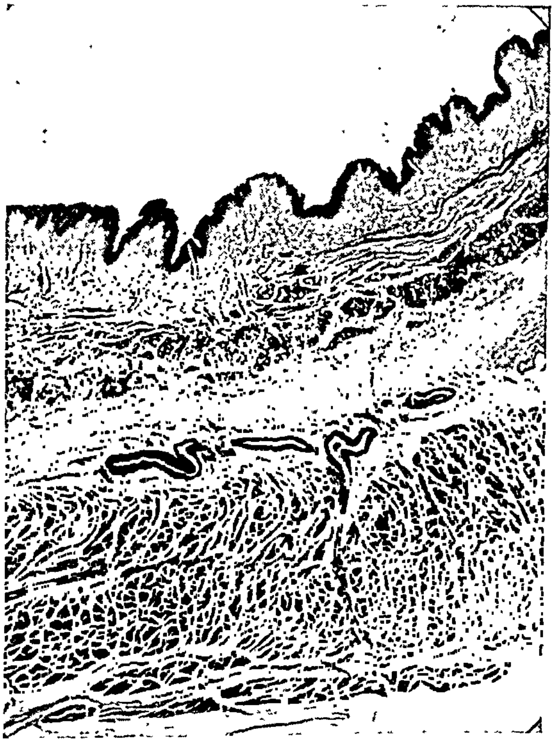

Fig. 14.—Normal wall layers of the esophagus (dog) as a comparison with Fig. 13.

but also of the surroundings This vasocontriction is followed by a period of spontaneous contractions (Zetler, Dontenwill) Owing to their relatively large requirement of oxygen, the ganglion cells are extremely sensitive to hypoxia and readily succumb Clinically this produces the picture of achalasia

Similar changes of the neural elements of the brain owing to hypoxia are *known, e g , following electro shock treatment and following the administration* of Cardiazol and vasopressin

SUMMARY

A clear conception of the normal anatomy and physiology of the region of the cardia is necessary for understanding the pathophysiology of achalasia

A review of the literature and personal experimental investigations suggested the following conclusions

1 In the region of the cardia there appears to be no anatomic sphincter *analogous to the pylorus, the vesical sphincter, or the anal sphincter* The closure of the esophagus is brought about by a number of factors, including the angle at which the esophagus enters the stomach with the formation of the plica cardiaca, and the natural tone of the cardia

2 The opening of the cardia at the end of deglutition is brought about by vagal fibers extending from the nucleus pigmentosus and innervating the striated musculature of the upper third of the esophagus They are not true parasympathetic fibers but, analogous to the motor fibers of the vagus innervating the larynx, occupy a special position in this nerve Their antagonist is not the sympathetic system but the neuromuscular system of the cardia itself which possesses considerable tone even in the resting state On irritation of the sympathetic system the tone of the cardia is increased but immediately decreases on termination of the irritation Even after operation with removal of all the sympathetic fibers, cardiac function is still normal

The *experiments showed that it is possible to produce experimental* achalasia simulating that seen in human beings On the basis of these experiments and studies of human cases of achalasia of recent origin and therefore early in development, it was possible to form a fairly clear opinion of the pathogenesis of the disease

1 Achalasia appears to originate in *Auerbach's* plexus with typical degeneration of the ganglia, agreeing entirely with the findings seen in early cases of human achalasia With this as a point of departure the mural layers of the cardia degenerate probably gradually, until they *reach the final* stage of degeneration described by Wanke as cardiac sclerosis

2 Judging by the human cases of early achalasia on record, there appears to exist an acquired form of achalasia

3 In the experiments described, the causal factor was chronic anoxemia with destruction of Auerbach's plexus as a consequence

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THE GASTROESOPHAGEAL SPHINCTER MECHANISM

II. Further Experimental Studies in the Dog

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Opinion varies as to the nature of the mechanism which normally prevents the reflux of gastric contents into the esophagus. Among the various hypotheses which have been advanced, the following seem most worthy of investigation: (1) an intrinsic gastroesophageal sphincter, (2) the acute esophagogastric angle, (3) the diaphragmatic "pinchcock," and (4) a mucosal valve or rosette.

Recent studies[4] from this laboratory showed that the diaphragm is not the major factor responsible for gastroesophageal continence, and further suggested that a sphincteric mechanism of undefined nature resides in the region of the esophagogastric junction. These studies did not indicate whether an intrinsic sphincter exists or whether the oblique entry of the esophagus into the stomach, associated perhaps with a valve flap of mucous membrane, is responsible.

It is the purpose of this paper to report further investigation concerning the nature of the mechanism responsible for gastroesophageal continence. In these studies, carried out on dogs, the various mechanisms mentioned were eliminated one by one in an attempt to define more exactly the mechanism of chief importance in prevention of reflux.

METHOD

Adult mongrel dogs were anesthetized with intravenously administered pentobarbital sodium (Nembutal); and in operations in which the thorax was opened, an intratracheal positive pressure apparatus was put in place.

Group I.—In animals of Group I the esophagogastric junction was removed and the esophagogastric anastomosis was made in different ways. In every dog the distal 2 cm. of esophagus and the proximal 2 cm. of stomach were removed. The anastomosis was made in two layers, with a continuous catgut suture for the mucosal layer and interrupted cotton sutures for the muscular layer.

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Group II—The acute esophagogastric angle was eliminated in animals of Group II by resection of the fundus or by division of the stomach 2 cm below the esophagogastric junction and anastomosis of the upper rim of the stomach to the top of the fundus

Group III—Animals in Group III underwent formation of a partial thoracic stomach The phrenoesophageal ligaments were incised and the diaphragm was attached to the stomach at a lower level, so as to eliminate the diaphragmatic pinchcock mechanism

Group IV—The mucosal rosette was eliminated in animals of Group IV, in addition to elimination of the acute esophagogastric angle, and the diaphragmatic pinchcock The stomach was divided 2 cm below the esophagogastric junction and the proximal rim of the stomach was anastomosed to the fundus In addition, the mucosa in both this small rim of stomach and the lower 1 cm of esophagus was removed and replaced by mucosa from the fundus

All dogs received penicillin and streptomycin intramuscularly after operation The dogs were given a liquid diet for a week and were fed a meat meal twice a day after that No other method to increase the output of hydrochloric acid was used because frequent feeding was considered more nearly physiologic than the injection of histamine

In all dogs, except those undergoing esophagogastrectomy, the vagus nerves were preserved One dog in Group I and 5 dogs in Group III died after the operation as a result of cutting through of the sutures between the stomach and the diaphragm In these dogs the stomach was found, dilated, in the thorax These dogs have not been included in the tables The dog in Group I died on the eighth day after the operation and did not show any esophagitis Esophagitis similarly did not develop in dogs in Group III

TABLE I RESECTION OF THE ESOPHAGOGASTRIC JUNCTION*

ADDITIONAL PROCEDURE	DOG	INITIAL ESOPHAGITIS AFTER DAYS	KILLED OR DIED AFTER DAYS	FINDINGS AT NECROPSY
I,A Anastomosis below the diaphragm	1	52 first examination	Killed 85	Linear esophagitis
	2	130 second examination	Killed 150	Linear esophagitis
	3	36 first examination	Killed 51	Linear esophagitis
I,B Anastomosis above diaphragm	4	45 first examination	Killed 78	Ulceration
	5	48 first examination	Killed 148	Linear esophagitis
	6	42 first examination	Killed 70	Ulceration
	7	- - - -	Died 25	Perforated ulcer
	8	- - - -	Died 15	Perforated ulcer
	9	- -	Died 29	Ulceration
I,C Creation of acute esophagogastric angle, anastomosis above diaphragm	10	- - -	Died 16	Ulceration
	11	- - -	Died 9	Ulceration
	12	- - -	Died 7	Perforated ulcer
	13	- - -	Died 7	Perforated ulcer
	14	- - -	Died 25	Linear esophagitis
	15	- - - -	Killed 27	Ulceration
I,D Narrowing distal esophagus, anastomosis below diaphragm	16	57 first examination	Killed 76	Ulceration
	17	- - - -	Died 38	Ulceration
	18	105 second examination	Killed 10	Line[illegible]agitis

*See also Fig 1

RESULTS

Group I. Removal of the Esophagogastric Junction.—

Although it has been frequently found that resection of the esophagogastric junction is followed by esophagitis, it was thought wise to perform this procedure in a number of dogs in order to learn if it was possible to prevent esophagitis by leaving the anastomosis below the diaphragm (Fig. 1 [I,A and D]), by forming a new sharp esophagogastric angle (Fig. 1 [I,C]), or by narrowing the distal part of the esophagus to half its circumference (Fig. 1 [I,D]). In 6 dogs the anastomosis was left above the diaphragm (Fig. 1 [I,B]). An acute angle was produced by suturing the fundus to the esophagus and in some

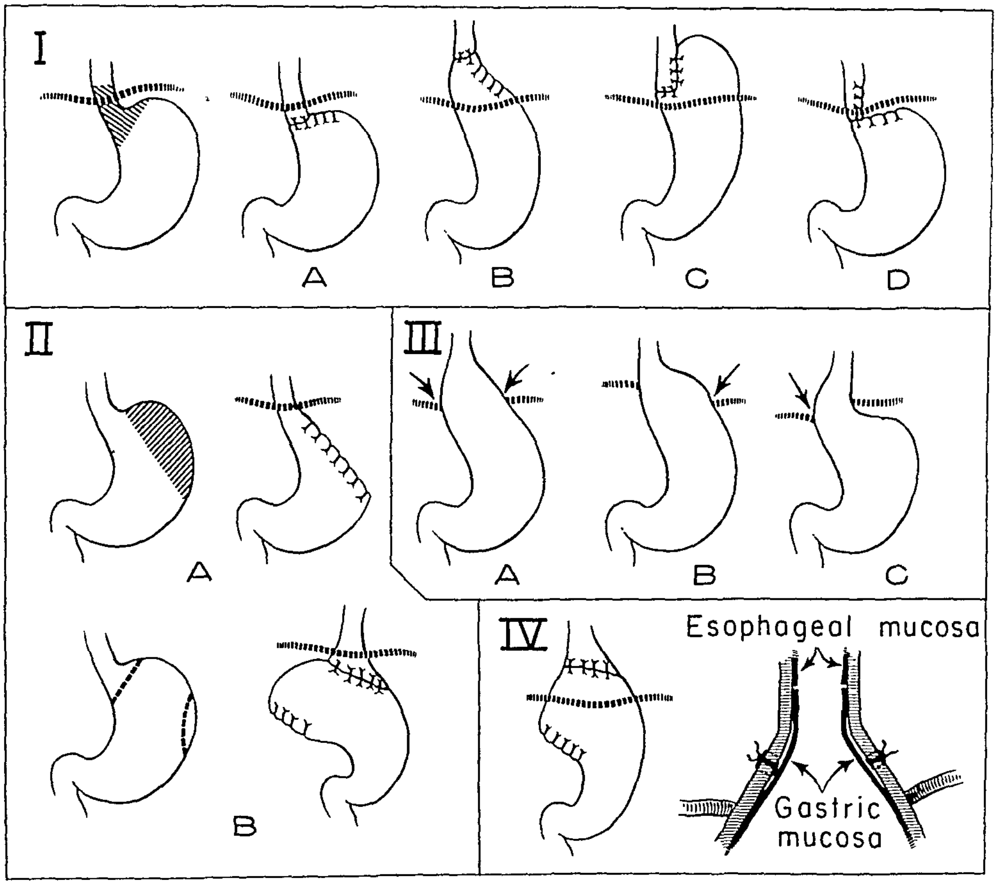

Fig. 1.—The experimental preparations used.

Group I. Resection of the esophagogastric junction with anastomosis below the diaphragm (*A* and *D*) above the diaphragm (*B*) with acute esophagogastric angle (*C*) and with narrowed distal esophagus (*D*).

Group II. Elimination of the acute angle. *A*, Resection of the fundus. *B*, Anastomosis of small upper rim of stomach to the fundus.

Group III. Elimination of the diaphragmatic pinchcock by division of both sides (*A*) or either side (*B* and *C*) of the phrenoesophageal ligament and reattachment of the diaphragm to the stomach at a lower level.

Group IV. Anastomosis of small upper rim of the stomach to the fundus, replacement of the mucosa in the upper rim of stomach and lower 1 cm. of esophagus by fundic mucosa. Anastomosis left in the thorax.

animals by fixing the angle by means of a band of fascia, attached to the diaphragm. The distal part of the esophagus was narrowed by excision of a triangular portion of the esophageal wall.

Esophagitis developed in all animals in this group (Fig. 2). It appears that the most severe degree of esophagitis developed in the shortest time in the dogs in which a new angle was made and in which the greatest part of the stomach was above the diaphragm (Table I).

Conclusion: An acute esophagogastric angle and the diaphragmatic pinchcock cannot prevent esophagitis after removal of the esophagogastric junction in dogs.

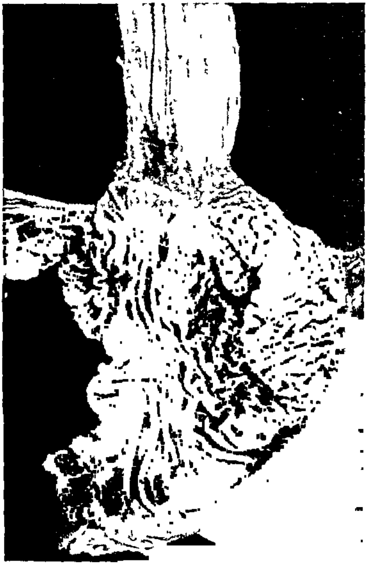

Fig. 2.—Specimen of stomach and esophagus of Dog No. 14 in Group I,C. The esophagus shows marked esophagitis with ulceration.

Group II. Elimination of the Acute Esophagogastric Angle.—

The esophagogastric angle was made obtuse in two ways to evaluate the importance of a sharp esophagogastric angle in the prevention of reflux. In some dogs the fundus was removed (Fig. 1 [II,A]). In the other dogs the stomach was transected 2 cm. below the gastroesophageal junction, and subsequently the proximal portion was anastomosed to the fundus (Fig. 1 [II,B]). Esophagitis did not develop in any of the dogs submitted to this procedure (Table II; Figs. 3 and 4,*a*).

TABLE II. ELIMINATION OF ACUTE ESOPHAGOGASTRIC ANGLES*

PROCEDURE	DOG	INITIAL ESOPHAGITIS, AFTER DAYS	KILLED, AFTER DAYS	FINDINGS AT NECROPSY
II,A Resection of fundus of stomach	19	--------	250	No esophagitis
	20	--------	144	No esophagitis
	21	--------	78	No esophagitis
	22	--------	78	No esophagitis
II,B Anastomosis of small upper rim of stomach to the fundus	23	--------	229	No esophagitis
	24	--------	194	No esophagitis
	25	--------	188	No esophagitis
	26	--------	287	No esophagitis

*See also Fig 1

Conclusion: An acute esophagogastric angle is not necessary to prevent reflux esophagitis in dogs.

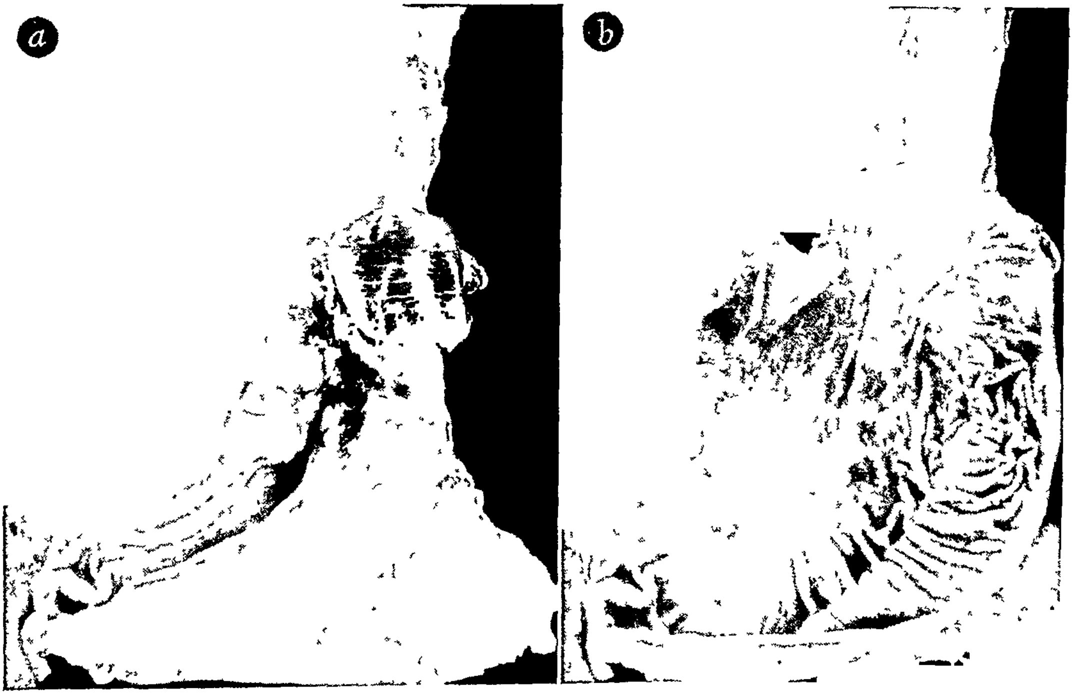

Fig. 3.—Specimen of stomach and esophagus of Dog No. 20 in Group II,A No esophagitis was found after resection of the fundus of the stomach *a*, Stomach incised but unopened *b*, Stomach and esophagus opened

Group III. Elimination of the Diaphragmatic Pinchcock.—

The diaphragmatic pinchcock was removed by division of both sides of the phrenoesophageal ligament in some dogs (Fig. 1 [III,A]), only the left in others (Fig. 1 [III,B]) and only the right side of this ligament in others (Fig. 1 [III,C]). In all, the stomach was placed in the thorax for a distance of about 3 or 4 cm. and the diaphragm was attached to it in the new position. Care was taken to leave a wide communication between the supradiaphragmatic and infradiaphragmatic portion of the stomach. The different procedures to

TABLE III. ELIMINATION OF DIAPHRAGMATIC PINCHCOCK*

PROCEDURE	DOG	INITIAL ESOPHAGITIS, AFTER DAYS	KILLED, AFTER DAYS	FINDINGS AT NECROPSY
III,A Both sides of phrenoesophageal ligament attached to stomach	27	--------	222	No esophagitis
	28	--------	83	No esophagitis
	29	--------	61	No esophagitis
	30	--------	59	No esophagitis
III,B Only left side of phrenoesophageal ligament attached to stomach	31	--------	117	No esophagitis
	32	--------	105	No esophagitis
	33	--------	103	No esophagitis
	34	--------	89	No esophagitis
	35	--------	74	No esophagitis
	36	--------	87	No esophagitis
III,C Only right side of phrenoesophageal ligament attached to stomach	37	--------	96	No esophagitis
	38	--------	96	No esophagitis

*See also Fig. 1.

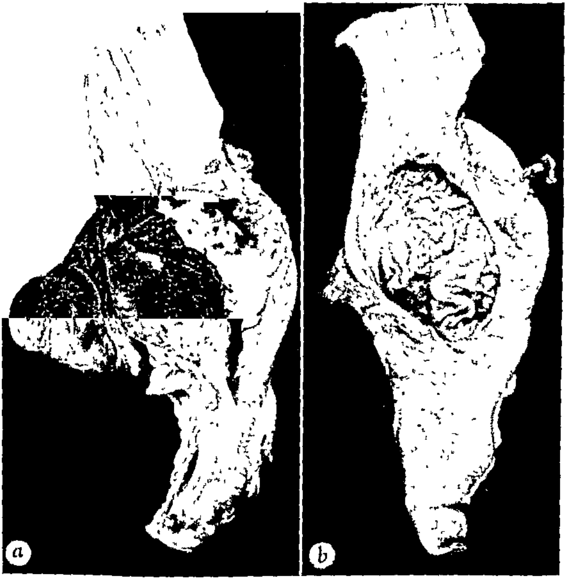

Fig. 4.—*a*, Specimen of stomach and esophagus of Dog No. 25 in Group II, B. No esophagitis was found after transposition of a small upper rim of stomach to the fundus. *b*, Specimen of stomach and esophagus of Dog No. 30 of Group III, A. Formation of a partial thoracic stomach was not followed by esophagitis.

obviate the diaphragmatic pinchcock were done because Guiseffi and associates[10] in this laboratory found marked esophagitis when they removed the muscle of the left portion of the right crus of the diaphragm.

Esophagitis did not develop in the dogs in the present study (Table III; Fig. 4,*b*).

Conclusion: The diaphragmatic pinchcock is not an essential mechanism for the prevention of reflux esophagitis in dogs.

Group IV. Elimination of the Mucosal Rosette in Addition to the Acute Esophagogastric Angle and Diaphragmatic Pinchcock.—

The stomach was cut 2 cm. below the esophagogastric junction and the mucosa in the small rim of stomach was removed, together with the mucosa of the distal 1 cm. of esophagus. This gastric rim was anastomosed to the fundus

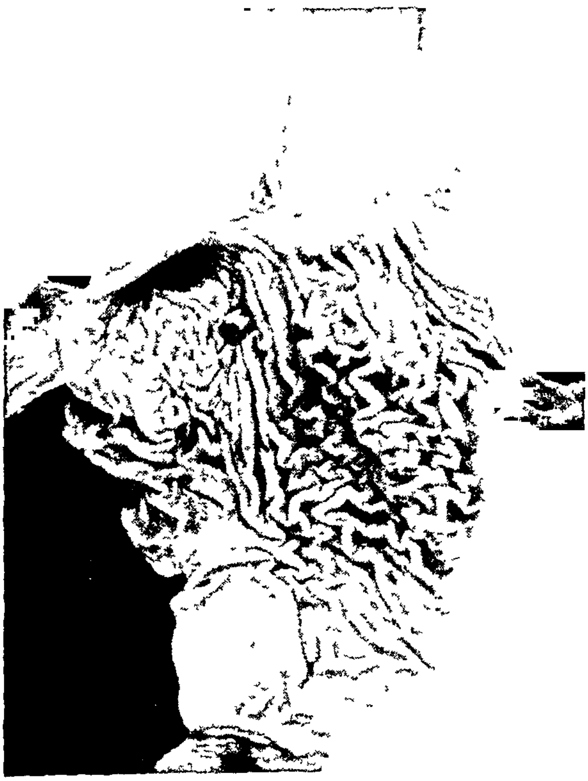

Fig 5.—Specimen of stomach and esophagus of Dog No 41 of Group IV No esophagitis was found when a small upper rim of stomach was anastomosed to the fundus, the mucosa of the upper rim of stomach and 1 cm of esophagus were replaced by fundic mucosa and the anastomosis was left in the thorax.

TABLE IV. ELIMINATION OF MUCOSAL VALVE OR ROSETTE IN ADDITION TO ACUTE ESOPHAGOGASTRIC ANGLE AND DIAPHRAGMATIC PINCHCOCK*

PROCEDURE	DOG	INITIAL ESOPHAGITIS, AFTER DAYS	KILLED, AFTER DAYS	FINDINGS AT NECROPSY
Anastomosis of small upper rim of stomach to fundus, replacing mucosa by fundic mucosa, anastomosis above the diaphragm	39	--------	83	No esophagitis
	40	--------	78	No esophagitis
	41	--------	75	No esophagitis
	42	--------	70	No esophagitis

*See also Fig 1

in such a way that mucosa from that part of the stomach replaced the mucosa previously removed The anastomosis was left 4 cm above the diaphragm (Fig 1 [IV]) Esophagitis did not develop in these dogs (Table IV, Fig 5)

Conclusion The acute esophagogastric angle, the diaphragmatic pinchcock, and a specific mucosal valve or rosette are not essential to prevent esophagitis in dogs An intrinsic sphincter mechanism in the region of the esophagogastric junction was the only possible mechanism which prevented esophagitis in this group

COMMENT

The acute esophagogastric angle, maintained by the diaphragm, was thought to play an important role in the prevention of reflux by Marchand,[13] who demonstrated that the pressure necessary to force fluids from the esophagus into the stomach was much less than that necessary to force it in the opposite direction The importance of the oblique entry of the esophagus into the stomach also was emphasized by Allison [1] Savage[15] found esophagitis in dogs in which he had removed the fundus of the stomach However, Hoag and associates[11] found that as long as a small rim of stomach was left distal to an intact esophagogastric junction, partial resection of the stomach was not followed by esophagitis, even though the acute gastroesophageal angle was eliminated Our findings are in keeping with those of these latter workers The acute esophagogastric angle does not appear necessary for the prevention of reflux in the dog

The importance of the diaphragmatic pinchcock mechanism in the prevention of reflux has been stressed by Jackson[12] and Allison,[1] among others Previous work from this laboratory by Braasch and one of us (Ellis)[4] discounted the importance of this mechanism, at least in dogs They created an abdominal esophagus in dogs by elevating the hiatus to a point 2 to 3 cm above the gastroesophageal junction Esophagitis did not develop in the animals, which suggested that something other than the diaphragm protected the distal part of the esophagus against reflux in these dogs Friesen and Miller[8] bypassed the esophagogastric junction in dogs, leaving the esophageal stump either above or below the diaphragm In their dogs, esophagitis developed above the esophagogastric anastomosis, but the esophageal stump remained entirely free from disease The same authors showed that formation of a partial thoracic stomach in dogs was followed by *esophagitis only when the hiatus was made very narrow* When esophagitis occurred it was accompanied by gastritis in the supradiaphragmatic portion of the stomach It would appear from their experiments that neither an acute esophagogastric angle nor the diaphragmatic pinchcock is necessary to prevent esophagitis in dogs The results of our own experiments confirm these findings

Guiseffi and associates,[10] however, did find esophagitis in dogs in which the phrenoesophageal ligament was not divided but in which the muscle bundle of the left side of the right diaphragmatic crus was removed In our experiments in which the phrenoesophageal ligament was cut and the diaphragm was attached to the stomach at a lower level, esophagitis did not develop An attempt was made to prevent obstruction of the supradiaphragmatic gastric pouch in our experiments, and this may account for the findings which differ from those of Guiseffi and associates.

Nauta[14] studied the movements of the esophagus by means of roentgen cinematography and by observing the cardia through a gastric fistula. He did not find any sphincterlike action in the distal part of the esophagus and concluded that the closure of the cardia is formed by a rosette of stomach mucosal folds, supported by a valvular mechanism as a result of the oblique entry of the esophagus into the stomach. On the other hand, Cohn and Magladry[6] removed the mucosa of 3 to 4 cm. of the distal part of the esophagus and covered the defect with gastric mucosa, brought up by submucous dissection. Esophagitis did not develop. These workers concluded that the mucosal rosette at the esophagogastric junction is not responsible for the prevention of reflux as long as the angle of entrance of the esophagus into the stomach is preserved.

The results of our experiments show that it is possible to remove the diaphragmatic pinchcock, to make the gastroesophageal angle obtuse and, in addition, to replace the mucosa at the gastroesophageal junction without the development of esophagitis. We therefore must conclude that an intrinsic mechanism, a sphincter, must be responsible for the remarkable fact that esophagitis was not found in any dog in our experiments unless the esophagogastric junction had been removed. Although most anatomists did not find a definite sphincter cardiae, Fyke and associates[9] and Atkinson and associates,[2] using the technique of intraluminal measurements of pressure, demonstrated the presence of a definite sphincteric mechanism at the esophagogastric junction in healthy persons. This mechanism recently has been demonstrated also in dogs.[16] Braasch and one of us (Ellis),[4] and Brackney and associates[5] showed that a long myotomy through the muscles of the esophagus and cardia may be followed by esophagitis in dogs. Presumably in these experiments the esophageal sphincter was completely divided.

Care should be exercised in applying the results of animal experiments to human beings. These experimental results, which emphasize an intrinsic sphincter mechanism as the important factor in the prevention of reflux, may seem at first glance to be at variance with clinical experience. The occurrence of esophagitis in patients with sliding esophageal hiatal hernia in whom, presumably, the intrinsic sphincter remains intact is well known. We share the opinion of Effler and Groves[7] on this problem, namely, that the diaphragm, placed in a position in which it can impair the passage of gastric contents between the supradiaphragmatic and infradiaphragmatic parts of the stomach, may lead to esophagitis in the presence of sliding hernia. Furthermore, Atkinson and his associates[3] have demonstrated, by studies of esophageal motility, a definite correlation between the height of the pressure barrier at the esophagogastric junction and the presence or absence of symptoms of reflux in patients with hiatus hernia. They concluded that the tone of the intrinsic sphincter is of cardinal importance in preventing reflux under these circumstances.

SUMMARY

Experiments were carried out in dogs to investigate the mechanism which prevents reflux esophagitis It was found that resection of the esophagogastric junction was followed by esophagitis in every instance Esophagitis was not prevented when the anastomosis was brought below the diaphragm, when the esophagus was narrowed, or when an acute angle was created between the esophagus and the stomach

Esophagitis did not develop when the acute esophagogastric angle was eliminated, the diaphragmatic pinchcock was removed and the mucosa at the esophagogastric junction was replaced by fundic mucosa It was concluded that a physiologic, if not an anatomic sphincter must reside in the region of the esophagogastric junction, independent of the diaphragm the acuteness of the esophagogastric angle and a specific mucosal valve or rosette The sphincter was found to be capable of preventing esophagitis in dogs under the conditions of these experiments

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MULTIPLE PRIMARY CANCER OF THE LUNG

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THIS STUDY presents 9 cases of dual primary cancer of the lung seen in a series of 500 cases of bronchial carcinoma at one Thoracic Surgical Unit. Multiple primary tumors of the lung have not been widely recognized or reported in the literature, yet with the gradual acceptance of air pollution and smoking as causative factors in the etiology of this disease, it is not surprising that multiple sites of origin should occur. As pulmonary cancer is now the commonest male cancer, its appearance in two lungs or twice in one lung might be expected.

Billroth[1] first drew attention to multiple primary malignant neoplasms at several sites, but his criteria of multiple malignancy were stringent and could not be applied to multiple tumors in a single organ. To satisfy a diagnosis of multiple primary malignancy he postulated that (1) each tumor must have an independent histologic appearance, (2) each tumor must arise in different situations, and (3) each tumor must produce its own metastases. Another rule, that of Mercanton, can only be applied to necropsy material: if, after the removal of two or more tumors, no further metastases develop, each tumor may be considered primary.

The criteria for diagnosing multiple primary tumors in this series have been macroscopic and microscopic independence. It is easy to distinguish macroscopic independence, but the difficulty in accepting the duality of origin of primary pulmonary cancer on histologic grounds depends on whether pleomorphism can be excluded in serial sections of any one tumor.

Several writers have discussed pleomorphism in bronchial carcinoma: Willis,[2] reporting on 84 necropsy cases, found a combined histologic pattern in 23 per cent or, conversely, an homogeneous pattern in 77 per cent; in 53 per cent of the cases of McGrath and others,[3] the tumor contained from 2 to 5 different histologic patterns, arranged in such a manner as to suggest initial independence and ultimate fusion—he concluded that neoplasms arose from more than one site and clinical recognition did not occur till coalescence of independent growths had been completed.

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More recently, however, Walter and Pryce[4, 5] have cleared the problem of pleomorphism in bronchial carcinoma—while some cases presented a complex histologic picture, by adhering to established criteria and examining numerous blocks from large tumors, they were able to classify all growths in their series into 5 types: oat cell, squamous cell, adenocarcinoma, polygonal cell carcinoma and a single rare type of metastasizing adenoma. Secondary changes such as squamous metaplasia, clear cell formation, and giant cell formation could be recognized as such in individual tumors, but did not obviate a classification into a single cell type.

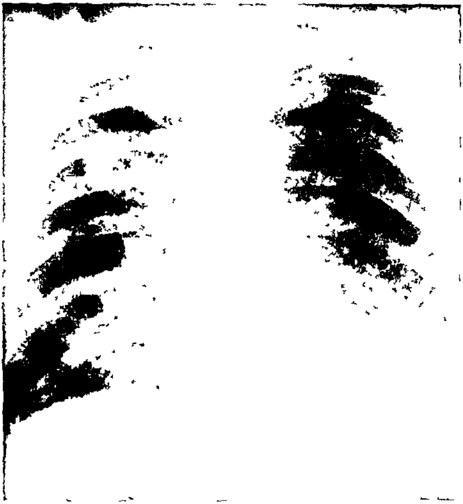


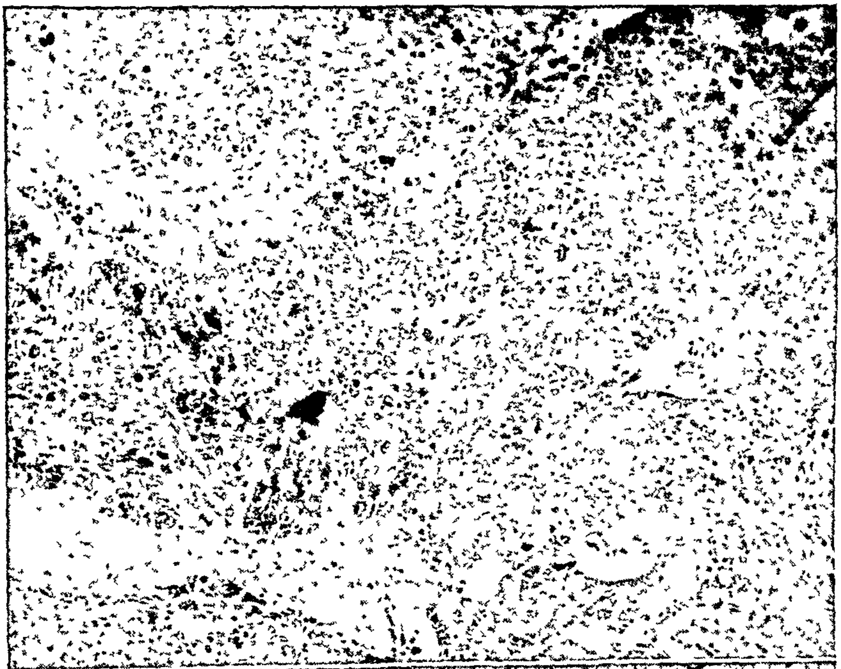
Fig 1.—Case 2. Roentgenogram showing cavitated lesion in the right upper lobe due to oat cell carcinoma and segmental shadow in the left posterior basal segment due to squamous cell carcinoma.

The histologic specimens in this series have been studied by three independent pathologists and have been considered to be sufficiently diverse as to represent dual primary cancer. The two primary cancers presented simultaneously in 8 patients, and in 1 the second developed 5 years after a presumed cure of a contralateral primary tumor by lobectomy. In 4 cases, the tumors were on the same side, and in 5 cases in opposite lungs. All the patients were males.

CASE REPORTS

Case 1.—A. H., aged 51, complained of recurrent staining of sputum and left chest pain. The admission radiograph showed partial deflation of the left lower lobe. Bronchoscopy showed an abnormal appearance in both lower lobe bronchi, consisting of edematous mucosa and nodular granulations. The biopsy fragment from the right [illegible] sh [illegible] squamous metaplasia, suggestive of neoplasm, and the left was normal. With treatment, the left side cleared but the right lower lobe showed partial deflation. A second bronchoscopy showed appearances similar to the previous one, with less inflammation. The biopsy from the left contained areas of oat cell carcinoma, and from the right, areas of inflammation and small fragments of growth. After consultation with several pathologists, it was agreed that a

Fig. 2.



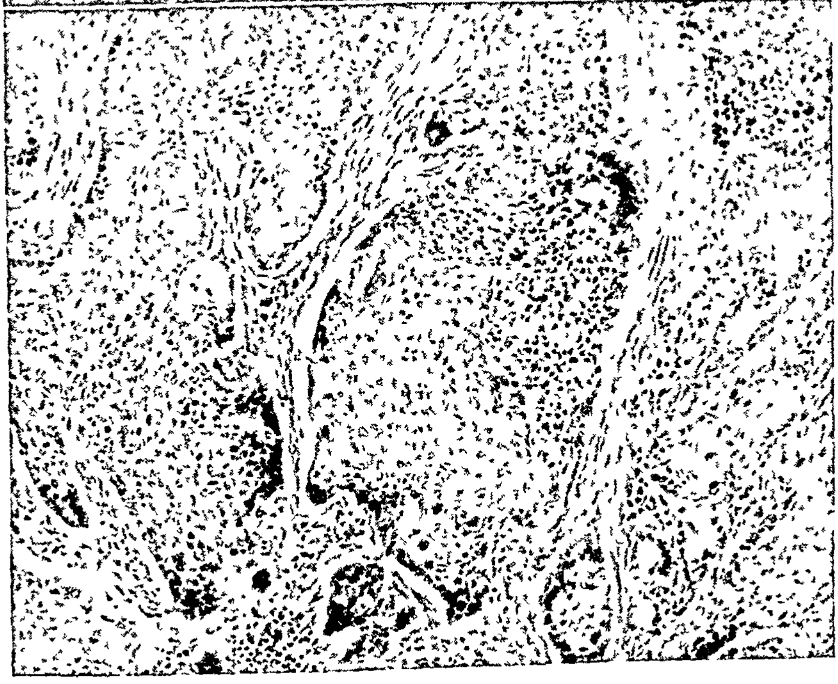


Fig. 3.

Fig. 2.—Case 3. Photomicrograph of left upper lobe tumor shows large oat cells (×103.)
Fig. 3.—Case 3. Photomicrograph of squamous cell tumor of left lower lobe. (×103.)

diagnosis of bilateral carcinoma was unlikely, and that the probable diagnosis was squamous metaplasia, associated with chronic inflammation This patient was returned to the care of his physician, and died one year later Necropsy revealed a large oat cell carcinoma of the left lower lobe while on the right side a small nodular squamous cell tumor partially obstructed the bronchus

Case 2—W C, aged 55, complained of cough and green sputum, hemoptysis on one occasion, and loss of weight A radiograph (Fig 1) showed a cavity in the right upper lobe and deflation of the posterior basal segment of the left lower lobe Initially he had been treated with antituberculous drugs After a month he had a massive hemoptysis requiring transfusion, and there was no radiological improvement—he was then treated as for an abscess of the right upper lobe with spill over into the left lower lobe Bronchoscopy a month later showed slight narrowing of the left lower lobe bronchus, the mucosa of which bled easily Blind biopsies were taken from the posterior basal segment and from a bleeding right upper lobe The histologic appearance of the tissue from the left lower lobe was that of squamous cell carcinoma and from the right upper lobe, oat cell carcinoma

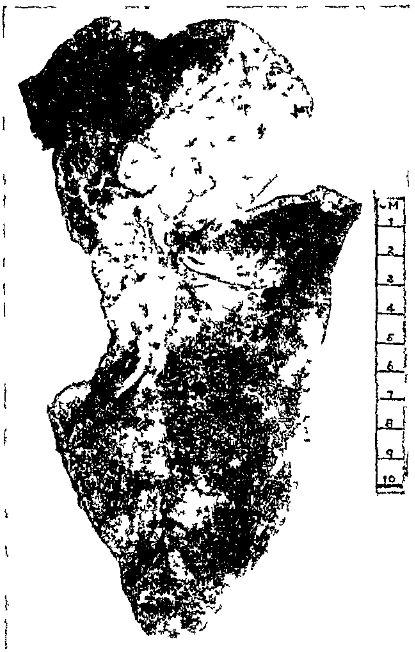
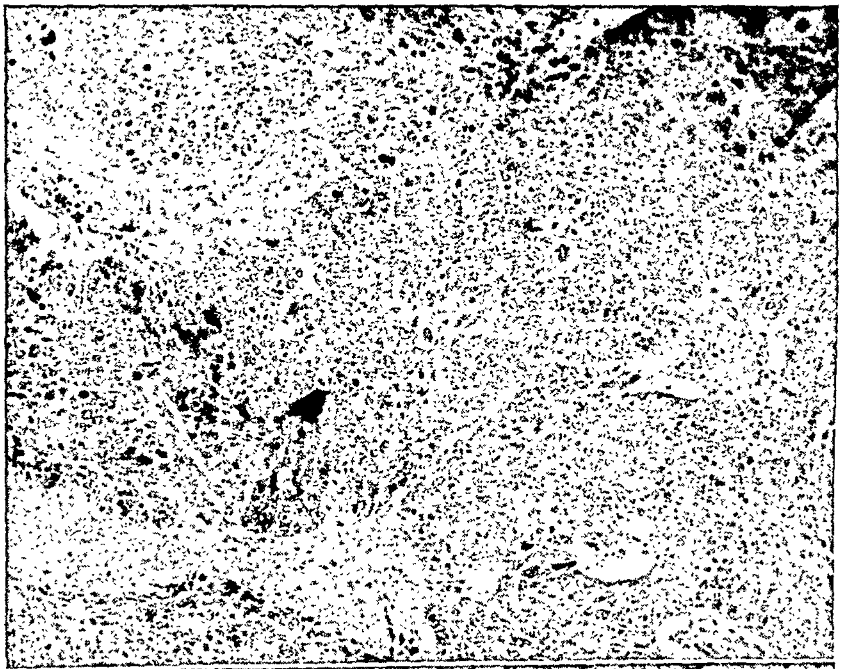


Fig 4—Case 4 Half lung section shows large tumor of left upper lobe (oat cell type) and smaller tumor in left lower lobe (squamous cell type)

He had a course of deep x ray therapy but he died a year later

Case 3—B C, aged 57, was admitted with a history of blood stained [illegible] m once and a cough for a month A radiograph showed peripheral shadows [illegible] t [illegible] e and metaplasia, suggestive of neoplasm, and the left was normal. With treatment, the left side cleared but the right lower lobe showed partial deflation. A second bronchoscopy showed appearances similar to the previous one, with less inflammation. The biopsy from the left contained areas of oat cell carcinoma, and from the right, areas of inflammation and small fragments of growth. After consultation with several pathologists, it was agreed that a

Fig. 2.



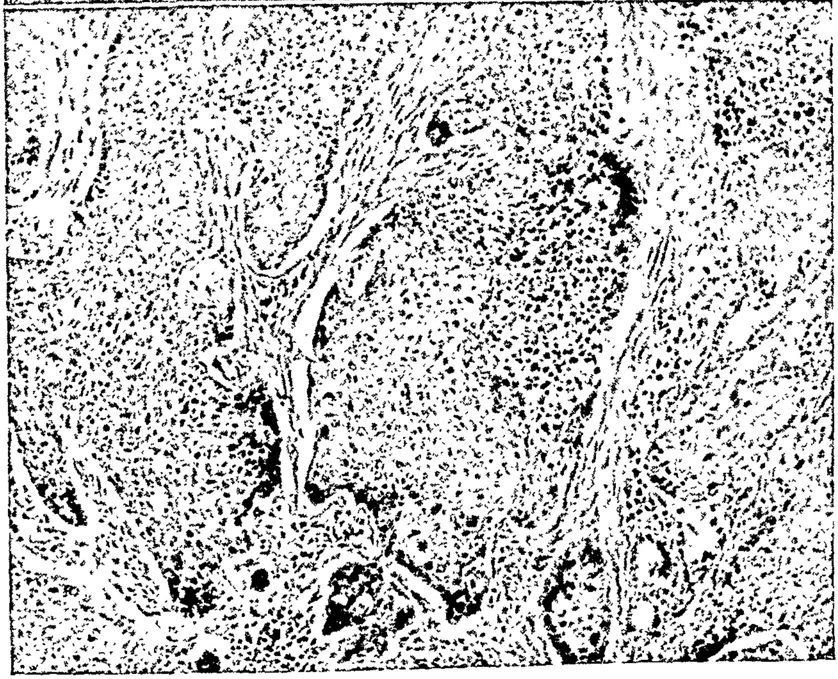


Fig. 3.

Fig. 2.—Case 3. Photomicrograph of left upper lobe tumor shows large oat cells. (×103.)
Fig. 3.—Case 3. Photomicrograph of squamous cell tumor of left lower lobe. (×103.)

diagnosis of bilateral carcinoma was unlikely, and that the probable diagnosis was squamous metaplasia, associated with chronic inflammation. This patient was returned to the care of his physician, and died one year later. Necropsy revealed a large oat cell carcinoma of the left lower lobe while on the right side a small nodular squamous cell tumor partially obstructed the bronchus.

Case 2.—W. C., aged 55, complained of cough and green sputum, hemoptysis on one occasion, and loss of weight. A radiograph (Fig. 1) showed a cavity in the right upper lobe and deflation of the posterior basal segment of the left lower lobe. Initially he had been treated with antituberculous drugs. After a month he had a massive hemoptysis requiring transfusion, and there was no radiological improvement—he was then treated as for an abscess of the right upper lobe with spill over into the left lower lobe. Bronchoscopy a month later showed slight narrowing of the left lower lobe bronchus, the mucosa of which bled easily. Blind biopsies were taken from the posterior basal segment and from a bleeding right upper lobe. The histologic appearance of the tissue from the left lower lobe was that of squamous cell carcinoma, and from the right upper lobe, oat cell carcinoma.

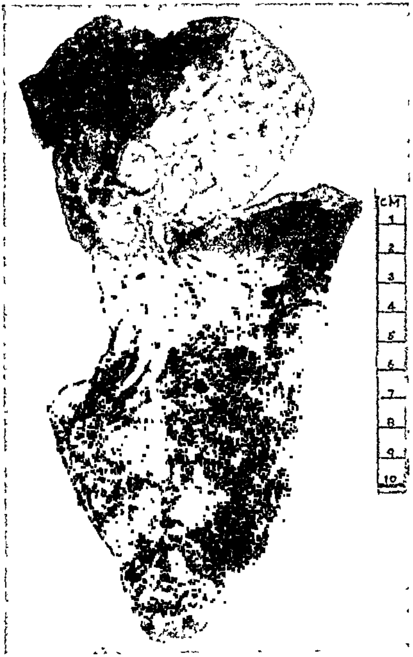


Fig. 4—Case 4 Half-lung section shows large tumor of left upper lobe (oat cell type) and smaller tumor in left lower lobe (squamous cell type).

He had a course of deep x ray therapy but he died a year later.

Case 3.—B. C., aged 57, was admitted with a history of blood-stained sputum once and a cough for a month. A radiograph showed peripheral shadows in the left upper lobe and left lower lobe. Bronchoscopy showed concentric narrowing of the left lower lobe bronchus, but the biopsy was negative. A left pneumonectomy was performed. Histologic studies revealed an oat cell carcinoma of the left upper lobe (Fig. 2) and a keratinizing squamous carcinoma of the left lower lobe (Fig. 3) with extensive involvement of lymph nodes.

This man died 2 years later of a recurrence.

CASE 4.—H. B., aged 55, complained of a dry cough for 6 months. A radiograph showed a large ill-defined opacity in the left upper lobe. Bronchoscopy was normal. A bronchogram showed an irregular rattail obstruction of the apicoposterior segment of the left upper lobe and a filling defect of the upper branch of the apical segment of the left lower lobe. A left pneumonectomy was performed. There was a large tumor in the upper lobe and a smaller tumor in the lower lobe (Fig. 4). Histologic study revealed the former to be of an oat cell type, and the latter to be squamous cell in type. He made a satisfactory early recovery, but died 2 months later of liver metastases.

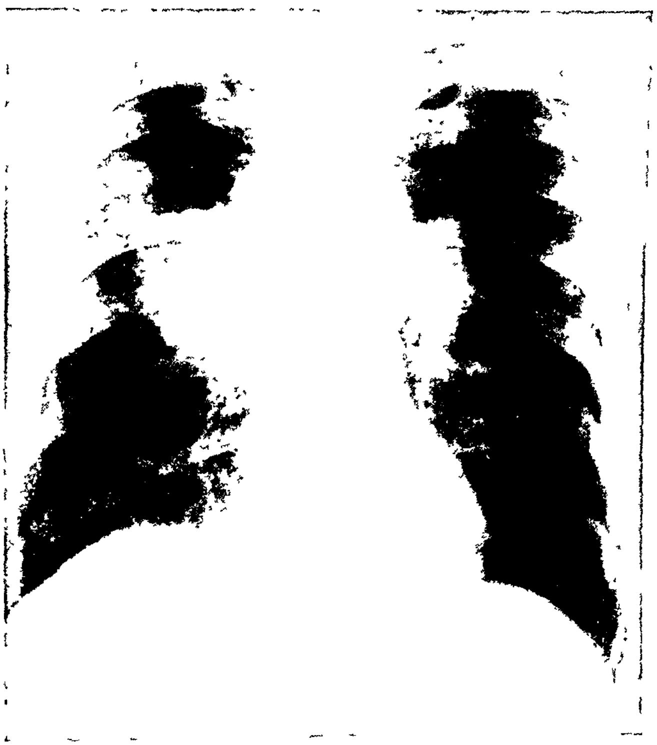


Fig. 5.—Case 7. Chest radiograph shows bilateral hilar shadows with a more peripheral shadow in the right upper lobe.

CASE 5.—A. K., aged 62, complained of dyspnea on exertion and tightness across the chest. A radiograph showed two peripheral shadows, seen best in the lateral film, one in the lingula and the other in the posterior basal segment of the lower lobe. Bronchoscopy was negative. A left pneumonectomy was performed easily. The lingular tumor was squamous in type, and the other oat cell in type. The patient is well and working.

CASE 6.—W. S., aged 46, was admitted with a small peripheral shadow in the right lower lobe for which a lower lobectomy was performed. The histologic appearance was that of a polygonal cell carcinoma. He remained in good health for over 5 years, when he developed sudden precordial pain and shock. A radiograph showed a segmental lesion in the left upper lobe. He died primarily from cardiac infarction, but a necropsy showed a pleomorphic carcinoma of the left upper lobe which was basically adenocarcinoma, with extensive invasion of lymph nodes, and metastases in the brain and kidneys.

CASE 7.—L. W., aged 64, complained of dyspnea on exertion and chest tightness. A radiograph showed hilar shadows in both upper lobes (Fig. 5). He collapsed and died suddenly before investigations were completed. Necropsy revealed a recent cardiac infarction, an oat cell carcinoma of the right upper lobe bronchus and a peripheral necrotic squamous carcinoma in the left upper lobe with extensive liver metastases.

CASE 8.—H. D., aged 62, complained of loss of weight and left inframammary pain on exertion. A radiograph showed shadows in the left upper lobe and the left lower lobe (Fig. 6). Bronchoscopy revealed growth protruding from the apicoposterior segment of the left upper lobe and narrowing of the left lower lobe bronchus. A palliative pneumonectomy was accomplished with difficulty. The upper lobe lesion was an oat cell tumor and the lower lobe contained an adenocarcinoma. He is at present well and working, 6 months after operation.

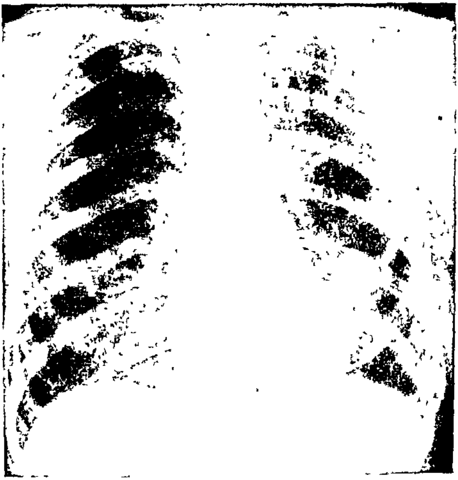


Fig. 6.—Case 8 Chest radiograph shows a peripheral lesion in the left lower lobe due to adenocarcinoma and a central lesion in the left upper lobe with distal infiltration due to an oat cell tumor.

CASE 9.—A. J. R., aged 80, was admitted in extremis and died the same day. A necropsy showed emphysema and bronchitis, with an oat cell carcinoma of the posterior basal segment of the right lower lobe, and a squamous carcinoma of the apical segment of the left upper lobe.

DISCUSSION

Dual carcinomata in other single organs (breast, colon, testis) have been occasionally reported. The incidence of multiple malignancy affecting all sites was estimated by Warren and Gates[6] as 1.84 per cent. This percentage resulted from analyzing several reported series, including surgical and necropsy material, and finding 546 satisfactory cases in 29,740 studied. When smaller series were examined (less than 500 cases) the incidence varied between 0.5 per cent and 4.3 per cent. Our 9 cases occurred in a series of 500 proved

INTRATHORACIC PHEOCHROMOCYTOMA

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The first case of pheochromocytoma successfully operated was reported by C. H. Mayo in 1927,[1] and the first correct preoperative diagnosis was made by Pincoffs,[2] in 1929. In Italy, operated cases have been reported by Giovanni Forni,[3] Valdoni,[4] Pampari,[5] Pettinari,[3] Ferrandu,[6] Calzolari,[3] Ceccarelli,[3] Fasiani,[7] Mauri,[7] Biancalana (2 cases),[8] and Paolucci.[9] This multiplication of observations is undoubtedly attributable not so much to a real increase in the incidence of this tumor as to a more precise and enlarged knowledge of the disease, and even more to numerous pharmacologic tests which, since 1945, have been made available for the diagnosis of pheochromocytoma. Kvale and co-workers[10] reported recently that in the course of the last 11 years in the Mayo Clinic, 7,933 patients with hypertension have been submitted to pharmacologic tests and to the estimation of the urinary catecholamines, and these examinations permitted the exact diagnosis of 51 cases of pheochromocytoma. Numerous cases have been incidentally discovered in the course of a bilateral sympathectomy performed for hypertension. According to Graham,[11] in his over-all review of pheochromocytoma, Smithwick, in the course of 1,700 sympathectomies, has discovered 7 cases of pheochromocytoma. It would appear that, if all patients with hypertension in whom pheochromocytoma may be suspected were submitted systematically to pharmacologic tests, the identification of this tumor could be made much more frequently.

For the pharmacologic test, we possess various substances, some of which are particularly suitable for the study of pheochromocytoma which cause a persistent hypertension, others more suited for the study of patients in whom the tumor provokes a paroxysmal hypertension. Among the former is phentolamine, or Regitine (Grimson, Longino, Kernodle, and O'Rear[12] and Gifford, Roth, and Kvale[13]) and piperoxan, or benzodioxane (Goldenberg, Snyder, and Aranow[14]), which block the hypertensive effect of noradrenalin and epinephrine. Among the latter there is histamine (Roth and Kvale[15]), tetraethylammonium bromide (La Due, Murison, and Pack[16]), and methacholine chloride, or Mecholyl (Guarnieri and Evans[17]), which cause a brusque influx in the circulation of norepinephrine and epinephrine.

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To these tests should be added the estimation of the urinary pressure amines which has been recently introduced and which will show itself of particular merit, but is technically very complex. According to Euler and Floding,[18, 19] the secretion of noradrenalin, which in normal subjects reaches 20 to 40 mcg in 24 hours, exceeds 100 to 200 mcg. in patients suffering from active pheochromocytoma. Less constant and less conspicuous is the increase in epinephrine secretion.

Such diagnostic means, having rendered the diagnosis of pheochromocytoma less difficult, have emphasized the difficulties inherent in the attempt at localization of the tumor. For establishing the site of the tumor, recourse has been had from the beginning to urography, to renal pneumography, and to retropneumoperitoneum. Recently, surgeons have tended to apply retropneumoperitoneum less and less frequently which, apart from its notable dangers, may give uncertain or fallacious results. They have limited themselves to a radiologic examination of the empty abdomen and to a urogram, and extended the surgical exploration in a systematic way to both sites of the kidneys which they approach by the transperitoneal route (Kvale, Roth, Manger, and Priestley[10]).

Such difficulties do not, however, beset the intrathoracic localization of the growth which is really the rarest of all and easily revealed by radiologic examination. It is the aim of this paper to describe a case of an intrathoracic pheochromocytoma (the seventh in the world literature) which had been diagnosed by us before the operation and in which the patient was then operated upon with full success.

CASE REPORT

V. O., 64 years old, was transferred to our department with the diagnosis of a neurogenic tumor of the posterior mediastinum.

For a year he had noticed a growing asthenia, a vague retrosternal pain, and dyspnea on exertion. His sleep became irregular, and often he would be overtaken during the night by anxiety, pulsating headache, and profuse perspiration. His body weight has undergone a notable reduction.

Examination revealed the obvious signs of arteriosclerosis, bradycardia (64 pulse beats per minute), and persistent hypertension, 180/120 mm. Hg. The electrocardiogram confirmed a sinus bradycardia and signs of left overloading. The laboratory tests were normal. Eye examination showed a hypertensive neuroretinitis of second degree.

Radiography of the thorax revealed the presence of an [illegible] mass of homogeneous density the size of half a mandarin orange situated in the right costovertebral [illegible] adjacent to the seventh and eighth thoracic vertebrae [illegible] a little [illegible] a process of erosion and compression. The lower edge of the mass merged into [illegible] of the mediastinal pleura. The shadow of the heart was enlarged due to a [illegible] the left ventricle, and the walls of the aorta were [illegible] (Fig. 1 [illegible]

The arterial blood pressure taken during one of the patient's [illegible] an increase to 220 mm Hg, and, thus, the presence of a pheochromocytoma [illegible] suspected. Thereupon the test with Regitine was carried [illegible]

On April 17, having taken all precautions [illegible] blood pressure, an anterolateral thoracotomy was [illegible] rib. The tumor was covered by the mediastinal [illegible] of the seventh and eighth vertebrae. Exploration [illegible] vascularized. After its removal (Fig. [illegible]

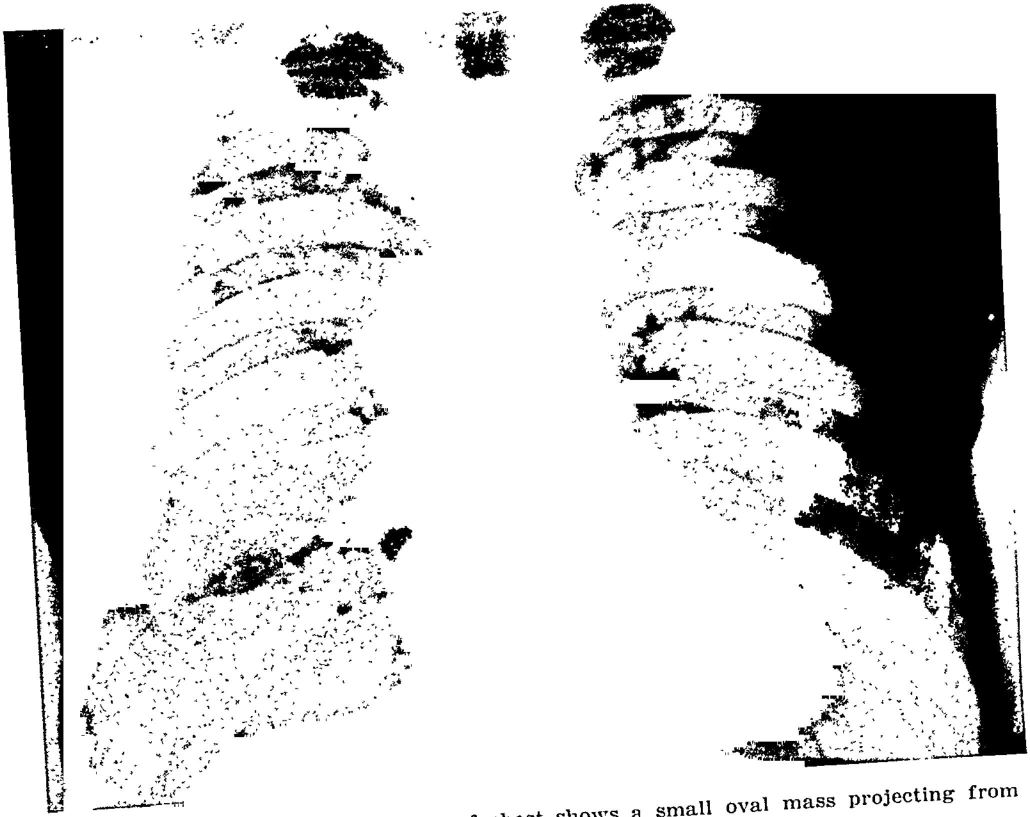


Fig. 1.—Posteroanterior roentgenogram of chest shows a small oval mass projecting from the mediastinal shadow.

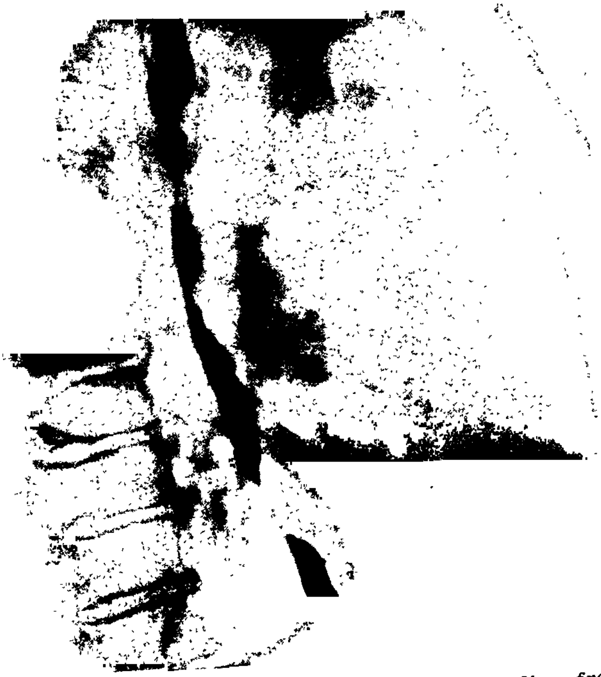


Fig. 2.—Lateral view shows mass in costovertebral region extending from seventh to eighth ribs.

followed an anxious alternation of improving and worsening of the heart action, which lasted for 1 hour and, at certain moments, required cardiac massage. After a transfusion of 1,800 c.c. of blood, introduced under pressure, and several administrations of Levophed, it was possible to raise the blood pressure to about 90 mm. Hg and eventually to bring about hemostasis. The operation lasted 2½ hours (Fig. 5). Undoubtedly, the cardiovascular symptoms produced by removal of the tumor were aggravated by the loss of blood amounting to about 1,200 c.c. and by the arteriosclerosis. The blood pressure reached 120 mm. Hg in the afternoon and, in the following days, became stabilized around 140 mm. Hg. After 3 months, the blood pressure was maintained at 140 to 145 mm.

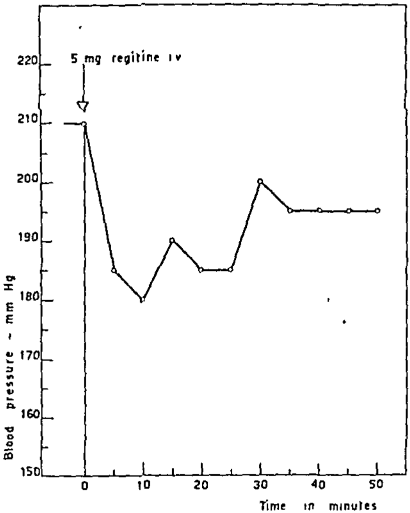


Fig 3.—Changes in blood pressure resulting from the intravenous administration of Regitine (5 mg.).

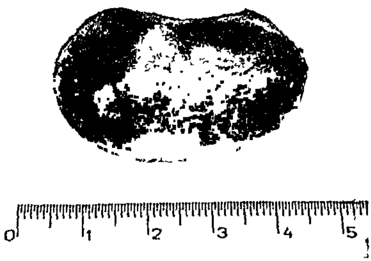


Fig. 4.—The pathologic specimen.

Histologic examination of the tumor showed the neoplastic tissue
a capsular sheath of sclerosed-hyalescent structure with sparse ce

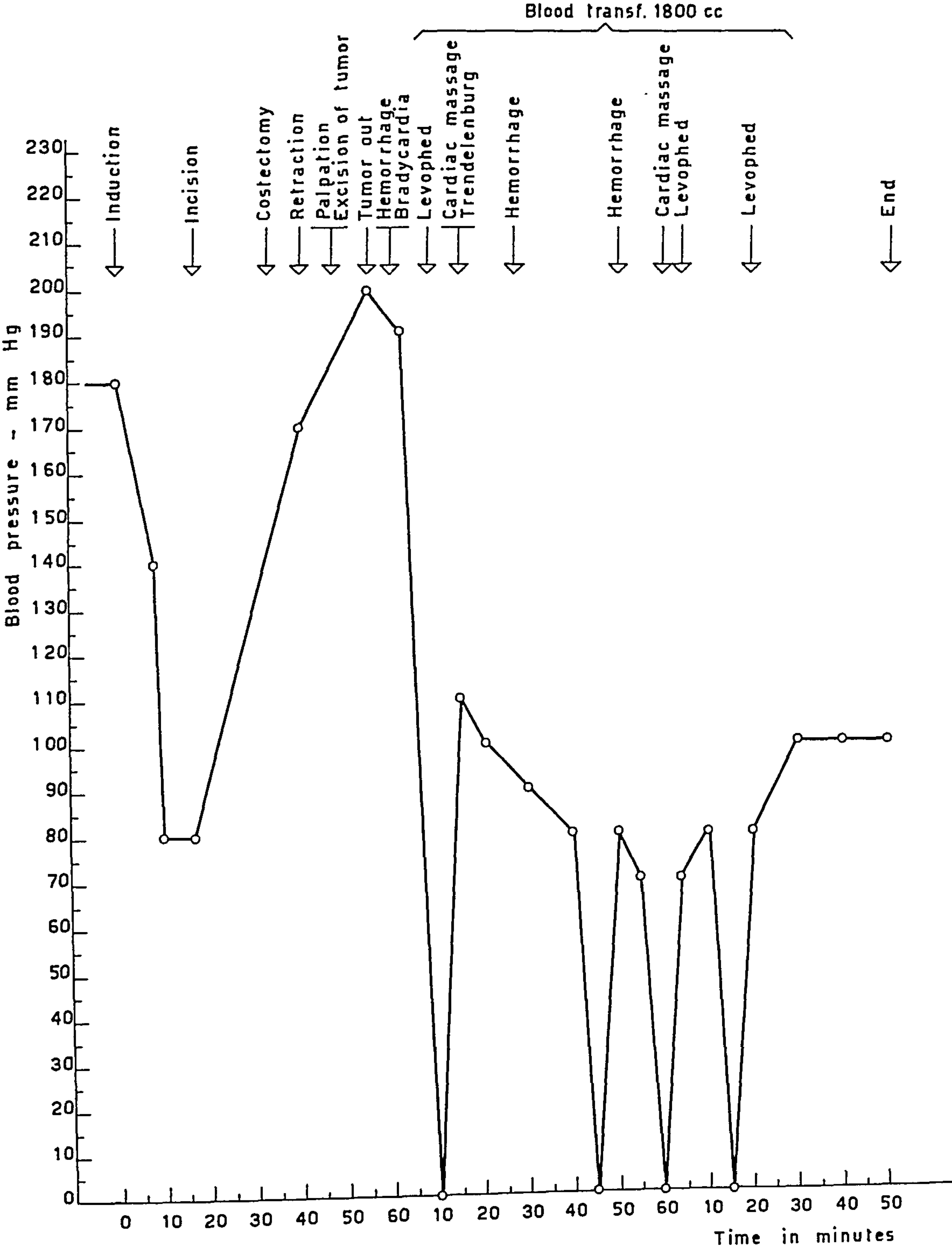
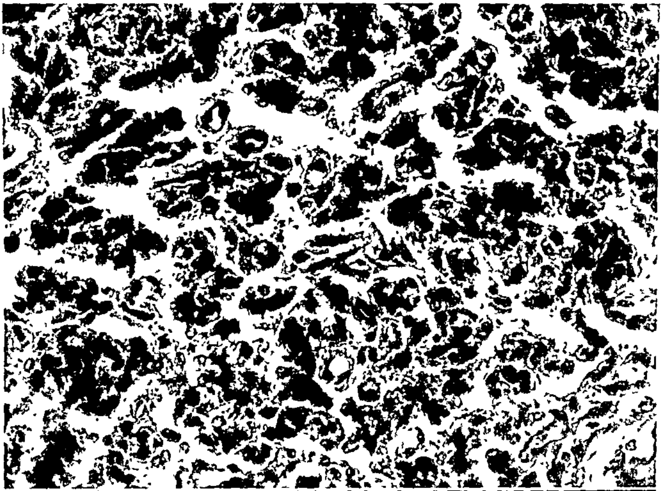


Fig. 5.—Changes in blood pressure during the operation.

Fig. 6.



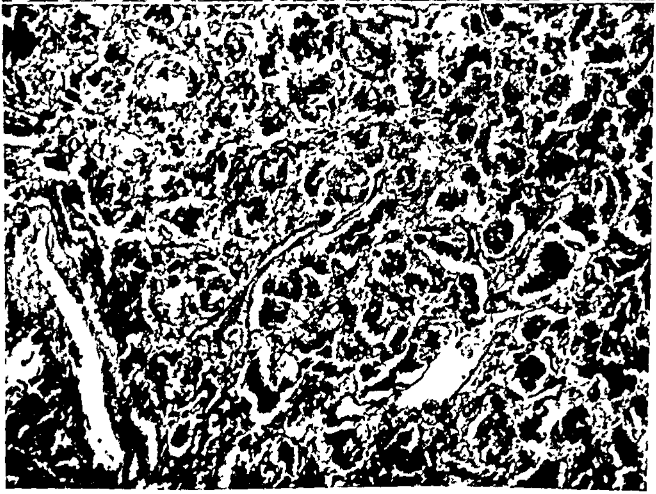


Fig 7.

Fig 6.—Photomicrograph of pheochromocytoma The characteristic arrangement of tumor cells in lobules separated by capillaries is shown.

Fig 7.—The chromaffin reaction (Bodian method).

traversed by vessels of indifferent aspect. The tumor tissue consisted of a collagenous stroma of variable development which, in some places, assumed a sclerosed and denser character, while in others it appeared quite scarce. The neoplastic cells which were arranged in columns or in alveolar formations, greatly differing in their size and shape, had a roundish or polygonal form and thin clear, slightly acidophilic cytoplasm, and indistinct contours. The nuclei had a rather rarefied chromatin network. Among these cells there could be discerned some which were conspicuous by their dimensions, and by their monstrous and gigantic appearance. Between the cell columns ran numerous capillary vessels which, in places, had an inspissated hyalinized wall with hypertrophic proliferating endothelial cells. In some zones extensive hemorrhagic infiltrations were visible. In a large area of the sections the presence of cartilaginous and bonelike tissue could be observed, consisting of inspissated lamellae and narrowed medullary lacunae. These tissues were, where they bordered the neoplasm, penetrated by neoplastic cells. The morphologic characteristics of the neoplastic cells, their arrangement in rows and alveoli, their intimate relation to capillaries, their similarity with medullary cells of the suprarenal glands, the presence of a capsule delimiting the growth, the benign morphologic aspect and clinical behavior of the tumor as well as its biologic behavior as a functioning growth, justified the diagnosis of pheochromocytoma (Fig. 6). The diagnosis was subsequently confirmed by the demonstration of the chromaffin reaction obtained with the method of Bodian (Fig. 7) (Professor Bini, Director of the Pathological Institute of the University in Parma).

In the literature there are 6 described cases of intrathoracic pheochromocytoma; 3 were found at necropsy while, in the remainder, the patients were successfully operated upon (Table I).

TABLE I

AUTHORS	SEX	AGE (YEARS)	LOCATION	PERSISTENT HYPERTENSION	PAROXYSMAL HYPERTENSION	RESULT
A. Cases of Intrathoracic Pheochromocytoma Diagnosed at Autopsy						
1. Miller (1924)	F	39	Right	?	?	
2. Philips (1940)	M	39	Left	-	Yes	
3. Wahl and Robinson (1943)*	M	4	Left	?	?	
B. Cases of Intrathoracic Pheochromocytoma Removed by Operation						
1. Maier (1949)	M	25	Left	Yes	-	Recovered
2. Overholt, Ramsay, and Meissner (1950)	M	16	Left	Normotensive		Recovered
3. Silvestrini, Genesi, Sachsel, and Costa (1957)†	F	39	Right	-	Yes	Recovered
4. Pampari and Lacerenza (1957)	M	64	Right	-	Yes	Recovered

*Sympathogonioma with mixed neuroblastic and pheochromoblastic elements, diffusely metastasized. Pheochromoblastic elements were present only in the primary growth.

†Operated upon by Fasiani.

SUMMARY

In every case of a posterior mediastinal tumor, associated with persistent or intermittent hypertension, the possibility of a pheochromocytoma should be kept in mind and the appropriate pharmacologic tests carried out to determine the diagnosis.

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PERIPHERAL LYMPHANGIOMA OF THE LUNG

F. G. Stephens, M.D., S. M. Roberts, M.D.,** and*
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In 1952, Worn[1] described a "cystic lymphangioma" within the pulmonary parenchyma and, in 1955, Giammalvo[2] presented a case of congenital lymphangiomatosis of the lung. We will present a third case of this rather rare lesion as illustrative of another type of solitary nodule to be considered in a differential diagnosis of single peripheral lesions of the lung.

REPORT OF A CASE

J. M. B., a 39-year-old white man, was admitted to this Veterans Administration Hospital on Jan. 25, 1957, as a transfer patient. He had been admitted previously to another facility on Sept. 11, 1951, for treatment of a duodenal ulcer, when a roentgenogram of the chest showed emphysematous blebs in the right apex but was otherwise normal. In 1956, a routine chest film (Fig. 1, *A*) had revealed an increased density, approximately 2.5 by 3.0 cm. in the left lung. The patient thought that he had had a slight increase in cough, but denied having had hemoptysis, dyspnea, fever, or weight loss.

Physical examination, which in general was negative, revealed a well-developed white man without dyspnea, orthopnea, or cough. Blood pressure was 140 systolic, 90 diastolic, pulse rate 80, and temperature was normal.

All laboratory examinations, including an electrocardiogram, were within normal limits. A planigram (Fig. 1, *B*) showed a lesion in the left lower lung field, extending from 7 through 15 cm. levels, which was well circumscribed, ovoid, smooth in outline, and of uniform fluid density. Skin tests for histoplasmosis, coccidioidomycosis, and blastomycosis were negative. Purified protein derivative in first strength was negative, reaction to second strength was 4 plus. Bronchoscopic examination was negative. Papanicolaou smears taken at bronchoscopy revealed no tumor cells. After a review by the tumor board, exploratory thoracotomy was recommended.

At operation the left chest was entered by means of a standard posterolateral incision through the bed of the fifth rib. Near the anterior aspect of the major fissure was a cyst, approximately 2 cm. by 2½ cm. This was in the fissure, covered by visceral pleura, but by palpation there appeared to be no connection with the major vascular or bronchial systems. Both by inspection and palpation, the entire lung and hilar area appeared normal. The cyst was readily removed by blunt and sharp dissection, without significant air leak, and with very little bleeding. The pleural space was drained by two catheters, followed by routine closure. The postoperative course was uneventful.

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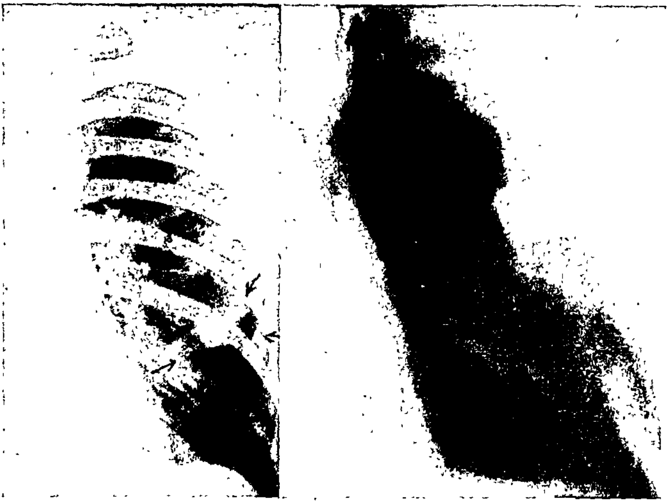

A. B.

Fig. 1.—*A*, Roentgenogram shows a well-circumscribed lesion in the left lower lung field, of uniform density, with fine threadlike strands radiating from the periphery. *B*, A planigram shows the lesion at the 12 centimeter level.

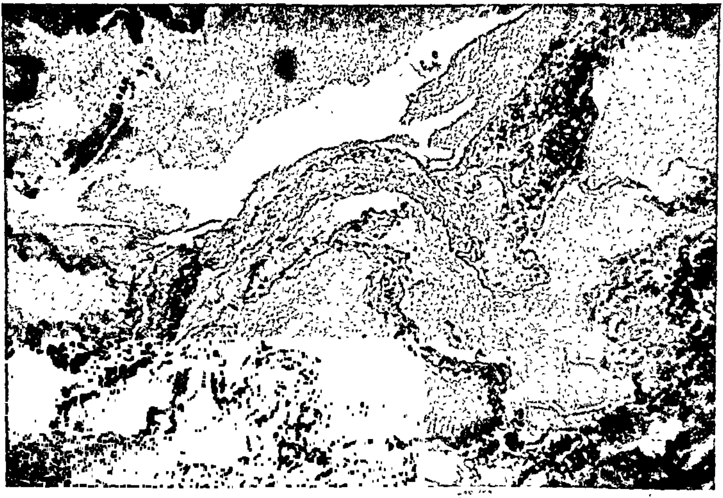

Fig. 2.—Microscopically the lesion showed thin walls and cystic spaces, some
dophilic precipitate.

Pathologic examination: The entire specimen was a fluctuant thin-walled cystic mass, 1.8 by 0.4 cm., completely encapsulated. To obviate loss of contents, the specimen was embedded without sectioning. Microscopically (Fig. 2), the periphery was composed of loose connective tissue. Irregular trabeculae extended from this and interlaced within the mass. These trabeculae were lined by flattened cells. The spaces between the strands were irregular and often contained an eosinophilic precipitate. Lymphocytes were noted in these spaces and, occasionally, lymphocytes and granulocytes occurred in small aggregates. Occasionally a small focus of lymphocytes was noted in the connective tissue of the walls.

SUMMARY

A case of lymphangioma of the lung is presented. This lesion may be due to mechanical blocking of the lymphatics with focal peripheral dilatation. In a young individual, a congenital defect or variation may be the pathogenesis of the lesion.

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ANTHRACO-SILICOSIS PRESENTING AS A SOLITARY PULMONARY LESION

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THE PURPOSE of this paper is to present a case of a solitary pulmonary lesion different from any previously encountered by the authors. No similar case has been found in the available literature.

CASE REPORT

B. B., a 59 year old white man, reported to the Out Patient Department of the Man Memorial Hospital with complaints of weakness and epigastric distress. As part of his study, chest radiographs were obtained and showed a rounded area of increased density, 4 cm. in diameter, in the posterior segment of the right upper lobe adjacent to the oblique fissure (Fig. 1, *A* and *B*). After surgical consultation, the patient was admitted to the hospital for study regarding this pulmonary lesion. He gave a 3 year history of an involuntary squint, entirely intermittent in nature. Previously he had been studied by a neurosurgeon who felt that the abnormality could not be based on any organic neurologic defect. He had had no operations or previous major illnesses. He never used tobacco of any kind. There was no recent change in weight. There was no family history of malignancy. Except for the noted involuntary squint, the physical examination was entirely normal.

Because of the possibility of this being a primary or secondary malignant lesion, numerous laboratory studies were performed. Complete blood count, urinalysis, serum bilirubin, thymol turbidity, prothrombin time, cephalin flocculation, serum amylase, glucose tolerance, gastric analysis, and nonprotein nitrogen were all within normal limits. Radiologic studies including a gastrointestinal series, excretory urogram, bone survey, barium enema, and gall bladder visualization were normal. Retrograde pyelogram and cystoscopy were also normal.

Because of the undiagnosed pulmonary lesion in the posterior segment of the right upper lobe bronchoscopy and exploratory thoracotomy were performed under general endotracheal anesthesia on July 30, 1957. Bronchoscopy was normal. A right posterolateral thoracotomy incision was made through the fourth intercostal space. Numerous fibrinous adhesions were divided throughout the entire right pleural space. All structures were normal except the right upper lobe where a lesion was noted occupying the entirety of the posterior segment with fixation to the interlobar fissure. The pulmonary lesion was hard, multilocular and multinodular. There was puckering of the visceral pleura. There was a gross appearance of malignancy. A right upper lobectomy was performed (Fig. 2). Frozen section diagnosis was a "benign infiltrate." Because of an extremely poor interlobar fissure and a purposeful sacrifice of portions of the right middle lobe, a middle lobectomy was then performed.

The patient made an uneventful postoperative recovery and was discharged from the hospital on his seventh postoperative day. Follow up examinations (Fig. 3, *A* and *B*) have been performed. He returned to full work as a coal miner 5 weeks after operation. He tolerates his work well, reports no dyspnea, and has no new complaints.

From the Man Memorial Hospital, Man, W. Va.

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Pathologic Report.—Specimen consists of the upper lobe of the right lung which showed near its periphery, adjacent to the surface in contact with the middle lobe, a round hard lesion measuring approximately 4 by 5 cm. On section it is found to contain approximately 15 c.c. of fluid with small black particles The cut surface is jet black and reveals an occasional small cystic space, the largest measuring approximately 0.8 cm. in diameter. A large amount of black material is found in the bronchus leading to the lesion The mass is fairly well circumscribed and solid. There is a line of sharp demarcation between the mass and the surrounding compressed lung. The second specimen consists of a resected middle lobe Near one edge, it appears more solid and more anthracotic than is usually encountered even in this geographic region.

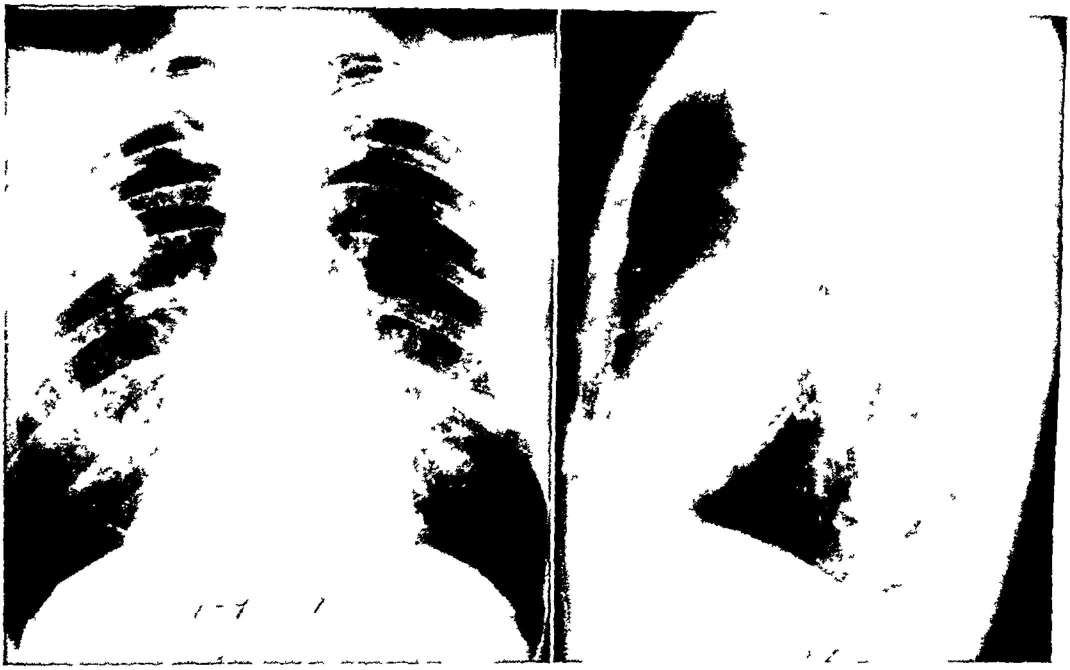

A *B*

Fig 1—*A* and *B*, Preoperative chest radiographs of Case 1

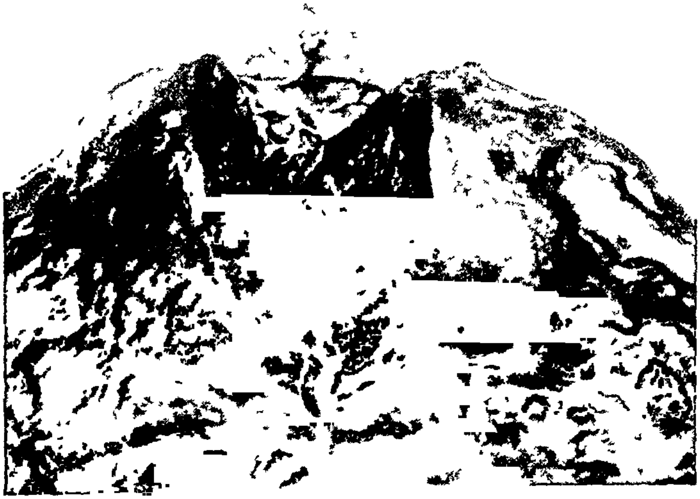
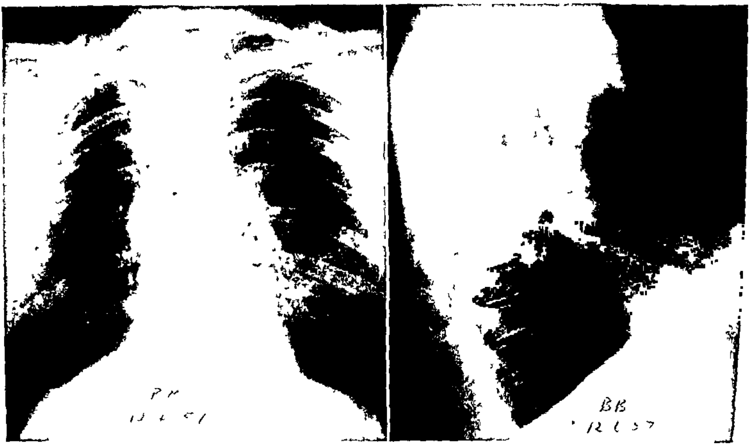


Fig 2—View of nodule resected in right upper lobe of Case 1

Microscopic sections reveal the solid portion of the tumor to be composed of connective tissue which is heavily pigmented throughout. In some areas, there is calcium deposited around the small cystic spaces described in the gross examination. The walls of these spaces are composed of dense scar. In other areas, there are cholesterol flecks. The blood vessels remain intact in most areas. The bronchi have for the most part disappeared. In the portion of the lung not involved in the tumor mass, there is moderate anthracosis

Diagnosis.—Anthraco-silicotic nodule, posterior segment, right upper lobe.

Review of the slides by Dr. V. E. Martens, Director of Laboratories, National Naval Medical Center, was reported as showing black anthracotic pigment and, under the polarizing microscope, refractile bodies which are typical of anthraco-silicotic nodules.



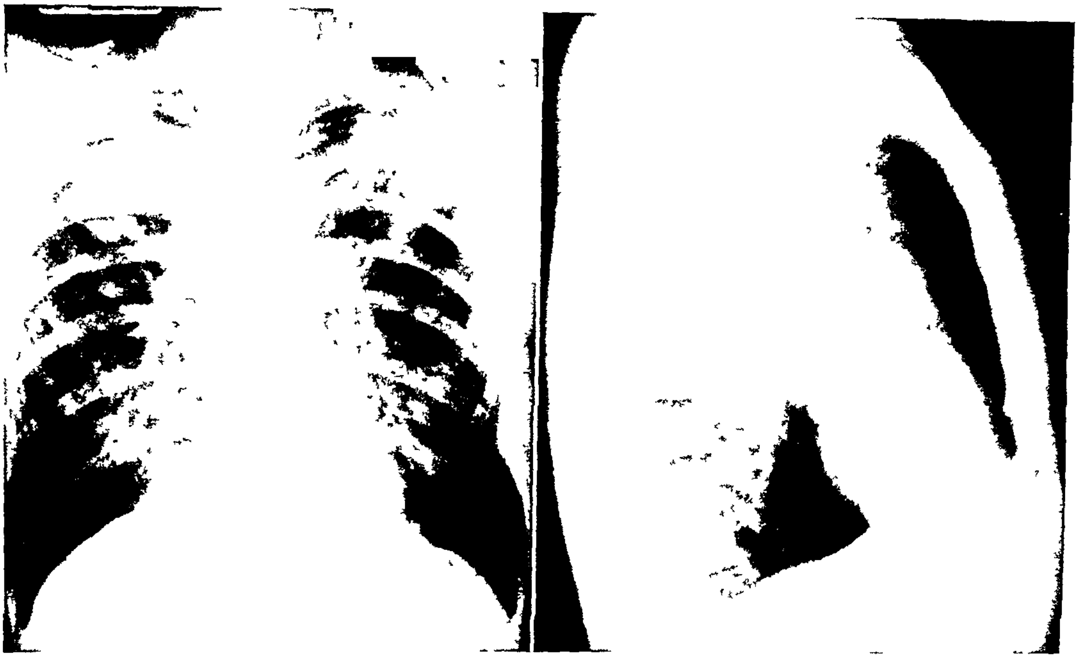
A *B*

Fig 3—*A* and *B*, Three months postoperative chest radiographs of Case 1

DISCUSSION

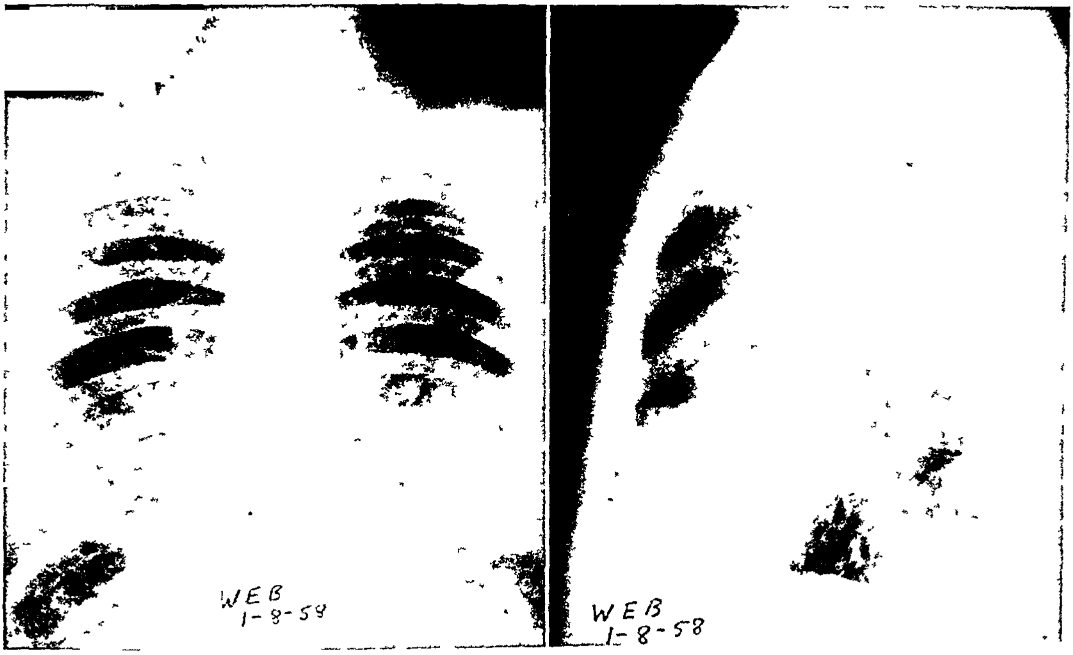
The diagnosis of solitary lesions in the lung is a subject which has received much attention in the literature. In December, 1956, Davis and co-workers reviewed their 215 cases and added them to an analysis of reported series totaling 1,203 cases No mention is made in any of these reports of a lesion due to any of the pneumoconioses. Pneumoconiosis is not included in the differential diagnosis of solitary pulmonary shadows in the Outline of Rad[illegible] Diagnosis compiled by the Resident staff at the University of Michigan

Recently the authors have encountered 2 men with problems [illegible] case presented here The diagnosis of anthraco-silicosis [illegible] logically (Figs 4, *A* and *B*, and 5, *A* and *B*) because of [illegible] were more definite diagnostic criteria of pneumoconiosis than [illegible] case in which the final diagnosis was not considered [illegible] logical, therefore, that an addition should be made to the [illegible] moconiosis presented in Table [illegible]



A *B.*

Fig 4.—*A* and *B*, Coal miner with definite radiologic diagnosis of pneumoconiosis showing a large, fairly discrete mass in the posterior segment of the right upper lobe. Case 2.



A *B.*

Fig 5.—*A* and *B*, Coal miner with radiologic evidence of pneumoconiosis with large, fairly discrete lesions in both lower lobes. Case 3.

TABLE I INTERNATIONAL CLASSIFICATION PNEUMOCONIOSIS

Simple Pneumoconiosis	
Category 1	In these radiographs a small number of opacities may be seen in at least two anterior rib spaces extending over not more than half of the medial two thirds of the lung fields
Category 2	In these radiographs, opacities extend over more than half of the medial two thirds of the lung fields but are sparse or absent in the lateral third
Category 3	In these radiographs, numerous opacities extend over the whole of both lungs including the lateral third, although they may be sparse or absent above the clavicle
Complicated Pneumoconiosis	
	Complicated pneumoconiosis or pneumoconiosis with coalesence or massive shadows
Category A	In these films opacities more than 1 cm in diameter may be seen in one or more areas, commonly coalescent, but not constituting a massive shadow of even density
Category B	In these films one or more massive shadows are present, extending over less than the equivalent of three anterior rib spaces on either side
Category C	In these films large massive shadows of uniform density extend over the equivalent of three or more anterior rib spaces on either side
Category D	In these radiographs, one of the more massive shadows is presented associated with gross distortion of the pulmonary anatomy The massive shadows may of themselves be such as to be classified A, B, or C in the absence of distortion

Since nowhere in the available literature and classifications of pneumoconiosis is there mention of isolated solitary lesions, a new category should be added The authors propose the term "Atypical Lesions" which could include solitary anthraco silicotic lesions occurring in lungs which otherwise show only minimal or even equivocal findings of pneumoconiosis, and solitary lesions occurring in lungs which show findings more diagnostic of pneumoconiosis We feel that future cases especially in our geographic area, will enlarge this section of the classification This seems especially probable since 3 such cases have been encountered in less than 6 months

SUMMARY

A case of a solitary pulmonary lesion due to anthraco silicosis is presented No mention of a similar entity has been found in either the literature on so tary pulmonary nodules or that on pneumoconiosis

It is proposed that this possibility be added to the differential diag sis of solitary pulmonary nodules especially in geographic areas in which eu moconiosis is encountered

It is also proposed that the classification of pneumoconiosis be enl ged include a category of "Atypical Lesions," such as the cases mentione in report

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THE SURGICAL TREATMENT OF PULMONARY TUBERCULOSIS COMPLICATED BY PULMONARY INSUFFICIENCY

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IN EVERY clinic engaged in the treatment of pulmonary tuberculosis there are many patients with pulmonary insufficiency. Of these, many can be cured with the aid of surgery, provided every effort is made to preserve function. Unfortunately, preservation of function is not always compatible with cure of tuberculosis. On the contrary, efforts to preserve function may actually have an adverse effect upon the patient's disease. Because of this, choice of procedure may be difficult. It is the purpose of this study to review our experience in the hope of facilitating such decisions by determining the indications and limitations of several procedures which we have employed.

MATERIALS AND METHODS

Three types of surgery have been employed at the Ray Brook State Tuberculosis Hospital in the treatment of patients with limited pulmonary function: plombage thoracoplasty, local cavitary resection (cavernectomy), and Monaldi drainage.[1]

Plombage thoracoplasty is employed with the intention of collapsing cavitary disease and as little functional lung as possible. Polyethylene beads are inserted into the subcostal space during the first stage. Beads are later removed only when infection occurs or resection is performed.

Cavernectomy consists of the removal of the cavity and the adjacent dense disease. In many patients with smooth "healed" cavities, who have received long-term preoperative combined antituberculous drug therapy, it has been possible to remove little more than the cavity wall (Fig. 1). In other patients with appreciable dense pericavitary disease, it has been necessary to perform segmental resection, or, less frequently, lobectomy. No attempt is made to remove all noncavitary disease and, in almost all instances, diseased lung has been transected.

Monaldi cavitary drainage is performed essentially as described by Woodruff and associates.[2] When the parietal and visceral pleura is known to be adherent, no preliminary rib resection is performed. Otherwise a small segment of rib and periosteum is resected and the formation of adhesions is encouraged by applying tincture of iodine to the parietal pleura in the rib bed. Every effort is made to avoid crossing pulmonary fissures when inserting the

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From the Ray Brook State Tuberculosis Hospital, Ray Brook, N. Y.
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catheter. Lower lobe cavities are approached from the axilla or posteriorly. In a number of instances in which local resection of cavitary disease has proved impossible at the time of exploratory thoracotomy, for reasons such as the proximity of important hilar structures, a small incision is made into the cavity and the tip of a 16 F double eye catheter is inserted. The opening is then closed about the catheter with several purse string sutures of atraumatic chromic 2-0 catgut. The last of these sutures is tied about the catheter. Suction is applied to the catheter with a bulb syringe to check for leaks as it is important that the closure be airtight. The other end of the catheter is brought out of the chest through a stab wound in the axilla. Immediate expansion of the lung is ensured by inserting two 28 F double eye rubber catheters into the pleural cavity. The tip of one is sutured by a single stitch to the anterior apical pleura and the tip of the other is led to the base posteriorly. These catheters are also brought out through stab wounds in the axilla. As soon as possible, about 40 cm. water suction is applied to the catheters in the pleural space and 20 cm. to the intrapulmonary cavity. The pleural tubes are removed usually in about 1 week. Suction is generally maintained continuously upon the cavernostomy tube for about 1 month. Following this the patient is allowed to walk about at intervals with the tube clamped.

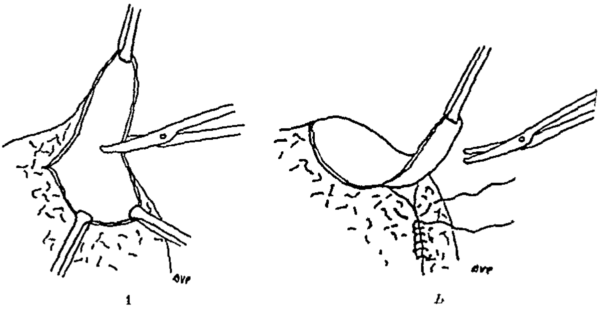

Fig. 1.—Method of locally excising a healed tuberculous cavity.
A, The cavity is unroofed. Bleeding is controlled with Allis clamps.
B, The floor of the cavity is excised with a small amount of adjacent lung tissue. The lung is progressively sutured with either interrupted 4-0 silk or continuous 2-0 atraumatic chromic catgut. Usually two layers of the latter suture are used.

Cavernostomy tubes are changed about once a month. Progress of cavity closure is determined at intervals by injecting iodized oil into the tube. Pneumoperitoneum is frequently administered as a supplement to tube cavernostomy. It is our present policy to remove the drainage tube after the sputum and cavity drainage have been negative for tubercle bacilli by culture for about 10 months, provided the cavity has closed. Whenever possible, combined antituberculous drug therapy is administered for at least a year concomitantly with cavernostomy. If only single drug coverage is available, drug therapy is not started until the cavity has been obliterated.

In order to determine the effect of residual disease upon the prognosis following local resection of cavitary lesions, Tables I and II have been compiled. To provide sufficient material for analysis, all of the resections for pulmonary tuberculosis performed at Ray Brook from January, 1950, to January, 1957, were reviewed. Resections which were not covered by antituberculous drugs and those concerning which sufficient information was not available were eliminated. Since it has been shown elsewhere[4, 5] that postoperative tuberculous complications may be influenced by the presence of tubercle bacilli at the time of surgery, and by the number of drugs administered, this information is included in the tables. Both early (*postoperative spread of* disease, empyema, and wound infection) and late (bacterial and roentgenographic relapse) tuberculous complications are listed together. A maximum of one tuberculous complication is attributed to each operation. The patients who had resections performed are divided into three groups according to the estimated amount of disease remaining after surgery: (1) *those with no* residual palpable disease on the side operated upon and no contralateral disease disclosed by roentgenogram; (2) those with "appreciable residual disease," that is, residual disease involving the equivalent of one half or more of one lung volume; and (3) an "intermediate group."

TABLE I. TUBERCULOUS COMPLICATIONS IN PULMONARY RESECTIONS PERFORMED UPON PATIENTS WITH CULTURABLE TUBERCLE BACILLI IN THE SPUTUM OR RESECTED TISSUE

NUMBER OF DRUGS WITH RESECTION	TOTAL		NO RESIDUAL DISEASE		"INTERMEDIATE GROUP"		"APPRECIABLE DISEASE"	
	COMPLICATIONS	NO COMPLICATIONS	COMPLICATIONS	NO COMPLICATIONS	COMPLICATIONS	NO COMPLICATIONS	COMPLICATIONS	NO COMPLICATIONS
One	20 (40%)	31 (60%)	1 (22%)	7 (88%)	6 (35%)	11 (65%)	13 (50%)	13 (50%)
Two or more	10 (14%)	64 (86%)	2 (9%)	20 (91%)	4 (20%)	16 (80%)	4 (13%)	28 (87%)
Total	30 (24%)	95 (76%)	3 (10%)	27 (90%)	10 (27%)	27 (73%)	17 (29%)	41 (71%)

TABLE II. TUBERCULOUS COMPLICATIONS IN PULMONARY RESECTIONS PERFORMED UPON PATIENTS WITH SPUTUM AND RESECTED TISSUE FREE OF CULTURABLE TUBERCLE BACILLI

NUMBER OF DRUGS WITH RESECTION	TOTAL		NO RESIDUAL DISEASE		"INTERMEDIATE GROUP"		"APPRECIABLE DISEASE"	
	COMPLICATIONS	NO COMPLICATIONS	COMPLICATIONS	NO COMPLICATIONS	COMPLICATIONS	NO COMPLICATIONS	COMPLICATIONS	NO COMPLICATIONS
One	2 (13%)	13 (87%)	0	5 (100%)	0	3 (100%)	2 (29%)	5 (71%)
Two or more	3 (1%)	284 (99%)	0	95 (100%)	2 (2%)	109 (98%)	1 (1%)	80 (99%)
Total	5 (2%)	297 (98%)	0	100 (100%)	2 (2%)	112 (98%)	3 (3%)	85 (97%)

Whenever drug therapy is discussed, only "effective" drugs are included, that is, only those drugs to which the patient's organisms were sensitive. Organisms are considered *sensitive* to streptomycin, para-aminosalicylic acid, or isoniazid, if they did not grow in the presence of 10 mcg. of the first two drugs or 5 mcg. of the last drug, respectively. Details of the bacteriological methods employed have been presented elsewhere.[5] Organisms are considered sensitive to viomycin, cycloserine, pyrazinamide, or tibione if the patient had not previously received them.

RESULTS

From the functional aspect, plombage thoracoplasty has much merit. If little functional lung is collapsed there is little decrease in ventilation. Moreover, during the early postoperative period, function is approximately as good as it is several months later.[6] Unfortunately this procedure has not cured many, in our experience. Between July, 1954, and July, 1957, this procedure was employed on 18 occasions at Ray Brook. Sixteen of these were on patients with far-advanced disease and 2 on patients with moderately advanced disease.* Of the 18, only 5 procedures succeeded in closing cavities. Of 13 procedures performed upon patients with infectious sputum, only 2 succeeded in converting the sputum to negative. Of the 5 patients in whom cavity closure was achieved, only 2 had infectious sputum at the time of surgery. The important role of antituberculous drug therapy is indicated by the fact that 4 of the 5 patients in whom cavity closure was achieved received concomitant drug therapy, while 9 of the 13 patients in whom cavity closure failed did not receive antituberculous drug therapy.

Surgical complications have been infrequent following this procedure. There have been no early postoperative spreads of disease. Two infections of the subcostal space occurred. Tubercle bacilli were cultured from one and *Bacillus proteus* from the other. Both of these healed promptly following removal of the foreign material and establishment of drainage. One patient died approximately 2 months postoperatively of cor pulmonale. Another patient died 6 months following surgery of hemorrhage from a contralateral cavity. Two patients died as a result of later surgery, one of a cardiac arrest during pulmonary decortication, and another as a result of attempted resection at another institution.

It is realized that these poor results reflect the extensive disease present. Nevertheless, since some of these patients were later successfully treated by resection of the cavity-bearing area, it would appear that the latter procedure is preferable if it is believed that the patient can tolerate it. For this reason it is our present policy to perform plombage thoracoplasty only when we believe resection would involve a great risk.

The ventilatory changes which occur with pulmonary resection have been reviewed elsewhere.[6] Briefly, there may be little permanent change if only nonfunctional lung is excised. The greatest disadvantage of resection lies in the often extreme temporary depression in ventilation which occurs in the early postoperative period.

The concept of treating pulmonary tuberculosis by attempting to obliterate cavitary disease is certainly not new. Early in our experience with resection for pulmonary tuberculosis,[7] it seemed that local excision of cavitary disease might yield good results. However, it soon became evident that results were not uniformly good, especially when appreciable amounts of residual disease remained. In Tables I and II, an attempt is made to determine the factors which influence the results of local cavitary excision. From Table II, it will be noted that tuberculous complications are uncommon in those patients who have had sufficient antituberculous drug therapy to render them noninfectious. All of these were late complications. On the other hand, Table I indicates a relatively high incidence of tuberculous complications in the patients who had infectious specimens or sputum at the time of surgery. In both tables the superiority of multiple drug therapy is apparent, although less so in the patients with noninfectious disease (Table II). Also, in both tables, the unfavorable effect of residual disease is apparent, although less so in the noninfectious patients (Table II). It would appear that the amount of residual disease influences results most unfavorably when only one antituberculous drug is given and when the sputum (or resected tissue) contains culturable tubercle bacilli. Conversely, the amount of residual disease is of only slight importance when the sputum and resected tissue do not yield culturable tubercle bacilli and when 2 or more antituberculous drugs are administered.

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*National Tuberculosis Association classification.

Six patients, included in Tables I and II, died of the following causes: cardiac arrest, postoperative intrapleural hemorrhage, hepatic necrosis (presumably the result of toxicity to pyrazinamide), pulmonary edema, coronary occlusion, and cirrhosis of the liver.

Monaldi cavernostomy can be performed by the percutaneous route with little effect upon pulmonary function. Of course, when it is performed at open thoracotomy, there follows a temporary depression in ventilation similar to that which occurs after pulmonary resection. Cavernostomy has yielded variable results, depending upon a number of factors. A review of 32 procedures performed upon 28 patients at Ray Brook between January, 1946, and July, 1957, reveals that all of the patients had infectious sputum at the time of Monaldi cavernostomy and in only 13 was a noninfectious state achieved. Of 15 procedures performed without concomitant antituberculous drug therapy, 14 failed to achieve negative cultures of the sputum. In the fifteenth case, the sputum became negative microscopically. Of 10 patients who received single antituberculous drug therapy, or less than 6 months of combined drug therapy, 6 developed noninfectious sputum. All 7 patients who received combined antituberculous drug therapy for over 6 months developed noninfectious sputum.

The value of posterolateral thoracoplasty as an adjunct to Monaldi cavernostomy is not evident. In this series, posterolateral thoracoplasty was performed on 19 occasions, following which the sputum became noninfectious in 8 instances. One additional patient developed microscopically negative sputum. Of the 13 instances in which posterolateral thoracoplasty was not performed, 5 patients developed noninfectious sputum. Neither these data nor Monaldi's experience[8] indicate that thoracoplasty is necessary in many cases.

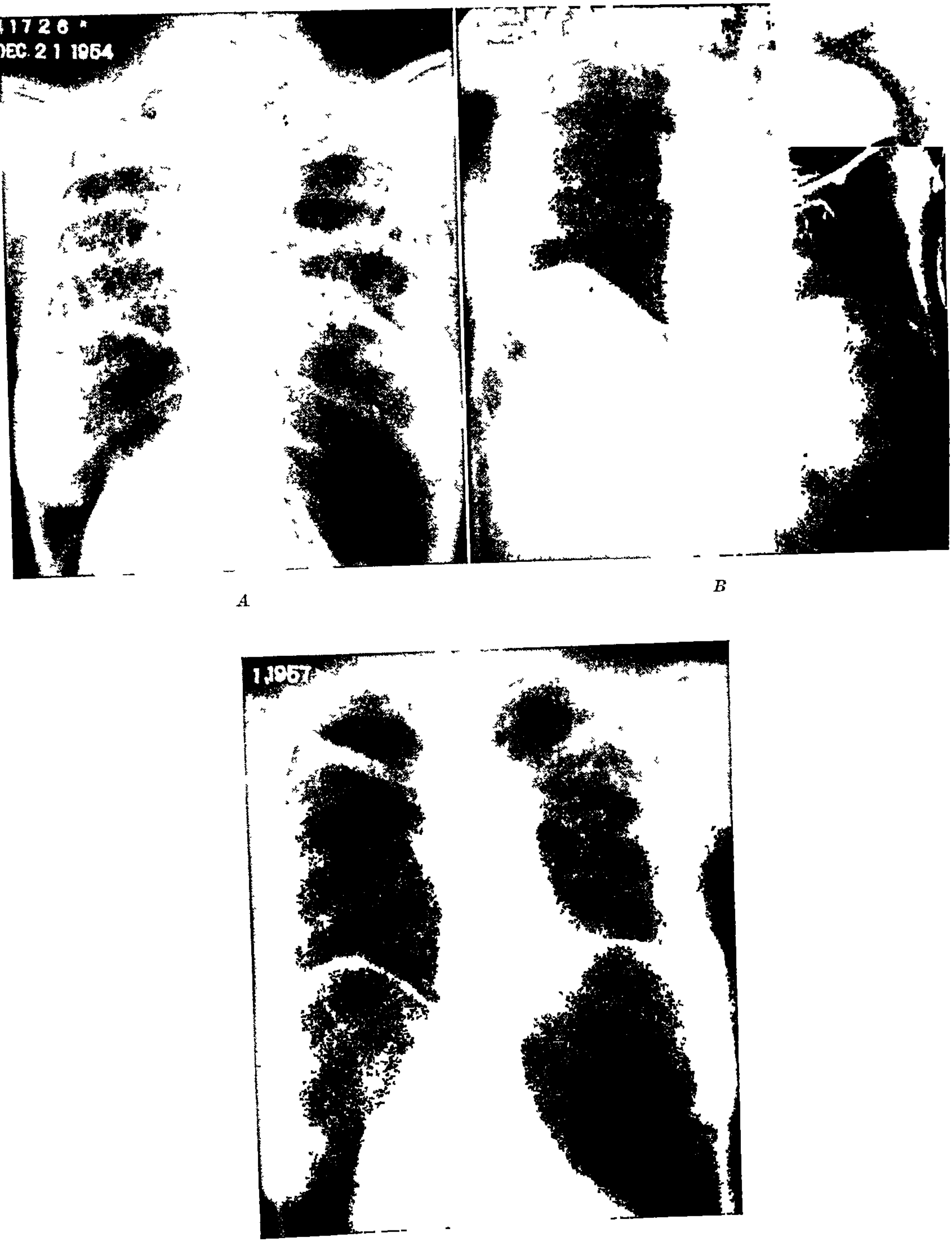
In this group of patients, complications have been limited to bleeding which was transient, except in one instance which terminated fatally. During bleeding episodes, suction is discontinued temporarily and the patient is encouraged to clear the bronchial tree by coughing gently. Few patients who have received concomitant antituberculous drugs have experienced this complication. Of the 28 patients treated by Monaldi cavernostomy, 7 are known to be dead. Six of these patients had failed to achieve noninfectious sputum; the other died of bronchogenic carcinoma.

REPRESENTATIVE CASES

CASE 1.—R. R., a 26-year-old woman, was admitted to Ray Brook State Tuberculosis Hospital on Nov. 15, 1954, with sputum containing tubercle bacilli resistant to streptomycin, para-aminosalicylic acid, and isoniazid. A roentgenogram of the chest revealed disease throughout both lung fields and large cavities bilaterally (Fig. 2, *A*). The patient was extremely ill and dyspneic. Pneumoperitoneum had been initiated prior to admission and was continued until March 16, 1957. On June 7, 1955, under local 1 per cent procaine anesthesia, a small segment of the left fourth rib with periosteum was removed through an incision in the axilla. The underlying pleura was wiped with tincture of iodine to create adhesions. On June 21, 1955, under fluoroscopic guidance with the aid of a trocar, a tube was inserted into the underlying pulmonary cavity through a small stab wound over the previously resected fourth rib. The cavity rapidly decreased in size and on Oct. 20, 1955, and again on Sept. 21, 1956 (Fig. 2, *B*), it could not be demonstrated by injection of iodized oil through the catheter. On June 8, 1956, pyrazinamide, 1 gram 3 times a day, and viomycin, 1 gram every 12 hours 2 days a week, were started. These drugs were continued until July 19, 1957. Vital capacity on June 22, 1956, was 1,300 c.c. total and 1,100 c.c. in 3 seconds. On June 29, 1956, right upper and middle lobectomy were performed, removing a large shaggy cavity which occupied both lobes. The postoperative course was uncomplicated and the sputum became noninfectious. The patient was discharged from the hospital on Jan. 18, 1958. Vital capacity on that day was 1,700 c.c. total and 1,400 c.c. in 3 seconds.

CASE 2.—B. P., a 32-year-old woman, was admitted to Ray Brook State Tuberculosis Hospital for the second time on Feb. 2, 1957. Her sputum contained tubercle bacilli which were resistant to 10 mcg. of para-aminosalicylic acid and 5 mcg. of isoniazid. Roentgenograms of the chest revealed diffuse disease in the left lung with cavitation in both lobes and a small amount of disease in the right lung. Vital capacity was 1,600 c.c. total and 1,000 c.c. in 3 seconds. On July 12, 1957, pyrazinamide, 1 gram three times a day, and cycloserine, 250 mg. every 12 hours, were substituted for para-aminosalicylic acid and isoniazid therapy which the patient had been receiving. On July 24, 1957, streptomycin was substituted for cycloserine. On July 22, 1957, a left exploratory thoracotomy was performed. Two cavitary areas were identified, one in the apical posterior segment of the upper lobe and one deep within the lower lobe. The lower lobe cavity was incised, revealing necrotic and purulent contents. It was obvious that this cavity could not be resected without sacrificing the whole lower lobe. Therefore, a 16 F. catheter was placed into the cavity and the incision was closed tightly about the catheter with sutures of 2-0 atraumatic chromic catgut. One suture was tied about the catheter. The apical posterior segment and a wedge of the anterior segment of the upper lobe were then resected. When this specimen was incised it revealed two cavities, one with a smooth glistening lining and one with a shaggy purulent membrane. Cultures of the former yielded no tubercle bacilli, those of the latter, many tubercle bacilli. Pneumoperitoneum was started on July 23, 1957. There were no postoperative complications. Following surgery, the patient's sputum became noninfectious. On Oct. 1, 1957, injection of iodized oil into the cavernostomy cavity failed to reveal evidence of cavitation, although a good bronchogram was obtained. Vital capacity on Jan. 24, 1958, was 1,700 c.c. total and 1,500 c.c. in 3 seconds.

CASE 3.—R. M., a 34-year-old man, was admitted to Ray Brook State Tuberculosis Hospital on Feb. 18, 1957, with tubercle bacilli resistant to streptomycin and para-aminosalicylic acid in his sputum. Chest roentgenograms revealed scattered noncavitary disease



A

B

C.

Fig. 2.—Roentgenograms of Case 1.

A, Appearance of disease before surgical treatment.

B, After a period of Monaldi drainage, no cavity is visible when iodized oil is injected into the catheter.

C, Roentgenogram following right upper and middle lobectomy.

involving the upper half of the right lung and two large cavities in the left upper lung field. In addition, there was scattered noncavitary disease in the remainder of the left lung. Fluoroscopy revealed evidence of obstructive emphysema bilaterally, worse on the left side. Vital capacity was 2,600 c.c. total and 2,000 c.c. in 3 seconds. On Oct. 18, 1957, viomycin, 1 gram every 12 hours 2 days a week, and pyrazinamide, 1 gram 3 times a day, were started. Isoniazid was not administered since the patient had been receiving the drug continuously for a prolonged period and it was thought possible that the patient's organisms might have developed resistance to the drug. On Oct. 25, 1957, a left pulmonary decortication and left upper lobectomy were performed. In addition, a large cavity with a smooth glistening membrane was removed from the lower lobe as illustrated in Fig. 1. The lung was sutured with two layers of continuous 2-0 atraumatic chromic catgut. When the upper lobe was incised, a large cavity with a shaggy purulent lining was demonstrated. The patient's postoperative course was not unusual except for the necessity of performing a 5-rib posterolateral thoracoplasty to obliterate an uninfected residual pleural air space. The sputum following resection became noninfectious. Vital capacity on Jan. 24, 1958, was 2,100 c.c. total and 1,500 c.c. in 3 seconds.

DISCUSSION

Ideally, surgery in patients with pulmonary insufficiency should remove tuberculous disease without sacrificing any functioning lung. Obviously no procedure can completely accomplish this, therefore, treatment of these patients requires various compromises. Occasionally, combinations of procedures must be used, such as segmental resection for a large rigid cavity and Monaldi cavernostomy for a smaller cavity which cannot be resected locally (Case 2), or lobectomy for extensive active disease involving a whole lobe, and local resection for a "healed" smooth-walled cavity in another lobe (Case 3).

Experience has shown that if cavitary disease can be excised, or otherwise obliterated, the remaining noncavitary disease is often well tolerated. Other factors being equal, there is an approximate quantitative relationship between the amount of disease and its effects upon the prognosis of the tuberculosis. However, the importance of residual disease varies with the bacteriologic state of the pulmonary tissue and the type of antituberculous drug therapy. The amount of disease is not very important when the lung has been rendered negative for culturable tubercle bacilli, a result which can be attained in the great majority of patients receiving long-term combined therapy with streptomycin, para-aminosalicylic acid, or isoniazid. The influence of residual disease upon prognosis is somewhat more important when culturable tubercle bacilli are present in the lung or sputum and long-term combined antituberculous drug therapy is administered postoperatively. The influence of residual disease is greatest in patients with infectious disease who receive single or short-term combined antituberculous drug therapy postoperatively.

From the functional point of view, percutaneous Monaldi cavernostomy is least disturbing to the patient. Open thoracotomy with concomitant tube cavernostomy or local resection of cavitary disease may be followed by little permanent decrease in ventilation. However, there is an early, often severe, decrease in ventilation which may not be tolerated well b[illegible]ith severe pulmonary insufficiency. This early decrease [illegible] city does not occur following plombage thoracoplasty and, for this reason, plombage thoracoplasty is well tolerated by severely ill patients, provided a minimal amount of functional lung is collapsed.

Following thoracotomy it may be necessary to perform a tracheotomy to tide the patient over the period of early depression of ventilatory capacity. By this means pulmonary dead space is decreased and tracheobronchial secretions can be aspirated. We have not found it necessary to employ mechanical respirators or assistors to date. After the Monaldi procedure, patients with poor ventilatory capacity usually find that they can cough more effectively if they occlude the cavernostomy tube while coughing.

Of the three types of procedures discussed, plombage thoracoplasty seems to offer the poorest therapeutic results. However, the procedure does seem to offer some degree of palliation by reducing the amount of sputum and fever in many patients who do not achieve a noninfectious state. An advantage of this procedure, shared with percutaneous Monaldi cavernostomy, is that it can be performed with relatively little risk in the absence of concomitant antituberculous drug therapy. If multiple antituberculous drug therapy is available, one can expect much better therapeutic results with local cavitary resection and/or tube cavernostomy.

SUMMARY

The surgical treatment of pulmonary tuberculosis in patients with pulmonary insufficiency requires that as much functional lung as possible be preserved. Three procedures meet these functional requirements: plombage thoracoplasty, local excision of cavitary disease, and Monaldi cavernostomy. These may be employed separately or in combination. Important factors which influence therapeutic results are the presence of bacilli, antituberculous drug therapy, elimination of cavitary disease, and the amount of residual disease. In our experience, resection of cavitary disease and Monaldi cavernostomy have generally been more effective therapeutically than plombage thoracoplasty. When antituberculous therapy is not available, open thoracotomy should not be performed.

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POSTPNEUMONECTOMY OLEOTHORAX

Karl P Klassen, M D , and Neil C Andrews, M D , Columbus, Ohio

THE POSTPNEUMONECTOMY pleural space presents a definite problem in the management of patients having undergone pulmonary resection for congenital, infectious, traumatic, and neoplastic diseases Because of the rigidity of the rib cage and instability of the mediastinum and diaphragm, it was generally assumed during the early days of pulmonary resection that with absorption of air and organization of the hemothorax, mediastinal shift to the side of resection would result in undesirable overdistention of the remaining lung Experimental proof was brought forth that in growing, experimental animals[1] such overdistention did not lead to impairment of pulmonary function but did in adult dogs Clinical investigation of patients having undergone pneumonectomy in childhood supported this finding[3] On the basis of clinical investigation,[4-7] it appears that such overdistention of normal pulmonary tissue in the adult is fairly well tolerated Severe pulmonary emphysema residual inflammatory disease, and other factors may, however, lead to progressive difficulties in the remaining lung[8, 9]

The fate of the pleural space following pulmonary resection is fairly well understood With adequate closure of the bronchial stump and chest wall, the pleural space will accumulate various amounts of blood depending upon the degree of trauma and hemostasis during surgery and on the type and duration of postoperative tube drainage With removal of the drainage tube and in the absence of bronchial leakage and infection the early absorption of air will lead to shift of the mediastinum and elevation of the diaphragm The resultant high negative pleural pressure may temporarily increase the amount of serosanguineous transudate However, eventually over a period of months the fluid is absorbed and the cellular element becomes organized into a contractile fibrothorax with narrowing of rib spaces marked mediastinal shift and elevation of the diaphragm Such contraction of the hemithorax may be minimal following a left pneumonectomy or in patients with preoperative diminution of the thorax due to long-standing previous congenital or infectious disease of the lung and pleura, and will present no particular problem Occasionally, however, particularly in adults following right pneumonectomy, a contracting fibrothorax may lead not only to overdistention of the remaining emphysematous lung but also to marked deviation of the upper mediastinal

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From The Division of Thoracic Surgery Department of Surgery The Ohio State [illegible] Health Center

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structures, interfering with the normal function of the superior vena cava, trachea, and esophagus. Elevation of the left diaphragm may lead to trapped gastric air syndrome and occasionally to cardiac irregularities.

The first pneumonectomy performed by Graham in 1933[10] for bronchogenic carcinoma was combined with a thoracoplasty for obliteration of the pleural space. Since that time numerous laboratory and clinical studies have been presented in an attempt to solve the problem of the postpneumonectomy space. The consensus appears to be that overdistention of an emphysematous lung will further decrease its function, that severe mediastinal shift is undesirable, and that late infection may occur in the residual space.

Thoracoplasty performed concomitantly with the primary resection[11-13] or as a later separate procedure[14, 15] is used extensively at the present time; however, it is associated with definite disadvantages. Prolongation of the operative time, increased surgical trauma, and subsequent increased operative and postoperative blood loss are important factors in the older age group in a concomitant thoracoplasty. Subsequent multiple rib resections carry the risk and expense of an additional operative procedure. The deformities of thoracoplasties are objectionable from a cosmetic standpoint, particularly in women of the younger age group.

To overcome the objections of thoracoplasty, various forms of prostheses or space-filling devices have been tried. In 1949, Johnson[16] advocated the use of plastic spheres introduced into the pleural space as a form of plombage. This prosthesis has been used extensively for extrapleural plombage as well as in the postresection pleural space. Although the initial results appeared satisfactory,[17] a few later reports indicated difficulties with this material.[18] Ivalon sponge shaped to fit the pleural space was suggested by Grindley and Waugh[19] and subsequently used by others[20,21] apparently with good results, although late reports again indicate that difficulties were encountered in the presence of pleural space infection.[15, 22]

In 1951, we[23] reported our experience with sterile olive oil used as a prosthesis in 20 patients following pneumonectomy. Over a period of many years olive oil had been used extensively for the maintenance of pulmonary collapse in tuberculosis. Difficulties encountered with its use were numerous and stemmed apparently from its application in patients with pleural infection and in the presence of bronchial fistulas. The oil itself appeared to be well tolerated and did not lead to tissue reaction such as was produced by paraffin oil.

Since 1950, oleothorax has been used in our clinic as a postpneumonectomy prosthesis in 123 additional cases and a follow-up report dealing with our experience appears indicated.

PROCEDURE FOR THE ESTABLISHMENT OF OLEOTHORAX

Immediately following pneumonectomy, intercostal underwater-seal drainage is instituted and continued for 24 to 48 hours for the removal of accumulated blood and for the maintenance of normal intrathoracic pressure.

Antibiotics are instilled into the pleural space on removal of the drainage tube and again just prior to discharge of the patient from the hospital, at which time the pleural pressure is neutralized.

The decision to establish an oleothorax is made during the postoperative period and depends upon preoperative pulmonary function, the condition of the remaining lung, the size of the pleural space, as well as on the operative findings and postoperative complications. Patients with previous contractile disease of the involved hemithorax and those with a small left pleural space and normal right lung usually show very little mediastinal shift and are not considered for oleothorax. Patients with known tuberculous pleural infection and with bronchial or cutaneous fistulas due to tuberculosis are treated by thoracoplasty. Patients with large residual pleural space, with emphysema or residual infection in the remaining lung and without evidence of pleural infection or [illegible] ratively are considered good candidates for [illegible]

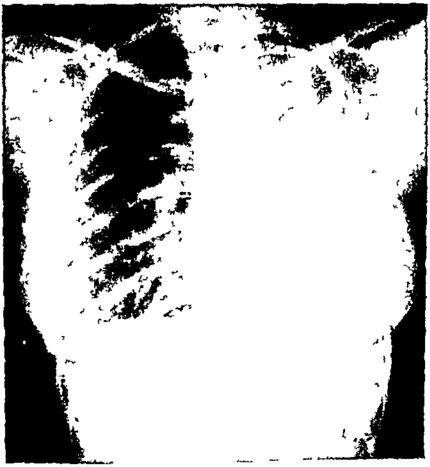

Fig. 1.—Roentgenogram showing excellent position of mediastinum 8 years following left pneumonectomy for tuberculosis and institution of oleothorax.

On re-admission to the hospital 4 to 5 weeks postoperatively, thoracentesis is performed using a No. 13 needle inserted through the seventh intercostal space in the midaxillary line. Following aspiration of the serosanguineous fluid, the patient is placed on the contralateral side and a second large needle is inserted for a distance of 2 cm. into the pleural space, one interspace above the first needle. This serves as an air vent. Sterile olive oil containing 1 Gm. of streptomycin and 300,000 units of penicillin per 500 c.c. is instilled into the pleural space through the first needle, using a 50 c.c. syringe. With the appearance of olive oil in the air vent needle, the instillation of oil is discontinued and both needles withdrawn. The amount of establishment of the oleothorax depends on the size of the hemithorax and has varied in our patients from 300 to 2,700 c.c., with an average of 880 c.c. in the 149 patients. Immediately following the injection of oil, fluoroscopy is performed to determine the position of the mediastinum. There is usually a small cap of air in the apex of the pleural space containing an estimated 150 c.c. of air which becomes absorbed over a period of several weeks. When performed properly, the instillation of the oil produced very little discomfort and the patient is discharged from the hospital 24 hours later.

The oil used in these patients was commercial olive oil sterilized by dry heat for 3 hours at 160° C. and allowed to cool to room temperature. Bacteriologic study of samples of oil prepared by this method has shown this to be adequate for sterilization.

All patients return for regular postoperative visits and roentgenograms are taken at yearly intervals. Absorption of the oil does not occur and the mediastinum is maintained in its original position (Fig. 1). No attempt is made to evaluate the pressure within the pleural space unless the patient develops symptoms suggesting infection or increased amount of fluid. On several occasions samples have been taken from the oleothorax, which, however, show clear white oil and no evidence of emulsification in the absence of infection. The pressure in the lower thorax is slightly positive with the patient in the erect position, with a negative pressure while the patient is recumbent.

RESULTS

Oleothorax was established in 149 of 313 patients undergoing pneumonectomy for various conditions (Table I). The majority of resections were performed for bronchogenic carcinoma and in more than half of them oleothorax was utilized as a pleural prosthesis. During the 10-year period of this study, thoracoplasty was not used concomitantly with or subsequent to resection for bronchogenic carcinoma except in 1 patient who developed an empyema with a cutaneous sinus following the establishment of oleothorax. Sixteen patients died within a 30-day period following resection while in an equal number extensive mediastinal and pleural involvement indicated a short life expectancy contraindicating the use of oleothorax. Among the above patients were 8 with bronchial fistulas. In 2 patients, an early pyogenic empyema developed which, after successful treatment with antibiotics, resulted in a fibrothorax with obliteration of the pleural space. Fluid could not be aspirated in 2 patients because of loculation, while 2 patients failed to return for the oleothorax. In 65 patients, oleothorax was not considered necessary because of excellent function of the remaining lung, good position of the mediastinum in the postoperative period, and a small fluid-filled pleural space. The majority of these were on the left side.

There were 6 patients in this group who developed difficulties following instillation of the olive oil. An immediate acute empyema resulted in 2 patients within 48 hours of the instillation of oil. Following aspiration of the oil and intensive pleural and systemic antibiotic therapy the space became

TABLE I. OLEOTHORAX FOLLOWING PNEUMONECTOMY, 1948-1958

DIAGNOSIS	NUMBER OF PNEUMONECTOMIES	OLEOTHORAX ESTABLISHED	COMPLICATIONS	
			EMPYEMA	FISTULA
Bronchogenic carcinoma	225	122	3	3*
Tuberculosis	70	14	1*	
Bronchiectasis	13	8		
Adenoma	2	2		
Chronic pneumonitis	2	2		
Cystic disease	1	1		
Totals	313	149	4	3

*Due to primary disease.

sterile over a period of several weeks. The oleothorax was re-established in 1, while a fibrothorax developed in the second patient. In both of these patients, subsequent investigation revealed that a portion of the olive oil used had not been sterilized. An empyema developed in 1 patient 2 weeks following the oleothorax, however, it responded to pleural antibiotic instillation without removal of the oil. In 2 patients, late empyema developed following formation of a bronchial fistula found at autopsy to be due to residual carcinoma of the bronchial stump. In one of these patients there was also present an esophageal fistula due to carcinoma. A cutaneous sinus at the site of tube drainage developed in 1 patient with the loss of the oil and formation of an empyema treated subsequently by thoracoplasty.

Autopsies were performed on several patients with oleothorax of several years' duration who had died of recurrence of the bronchogenic carcinoma with extensive metastasis. The pleural space was found to contain a clear oil of approximately the amount instilled previously. The pleural surface was smooth and glistening, and microscopic sections showed a fibrous membrane containing oil spaces and very little inflammatory reaction (Fig. 2).

At the present time there are 75 patients alive with oleothorax who have had resection for bronchogenic carcinoma. The longest survival is 10 years (Fig. 3). Forty-seven patients died at various intervals, following pneumonectomy and oleothorax, of progression of their bronchogenic carcinoma.

Pneumonectomy was performed in 70 patients with tuberculosis for destroyed lung, extensive excavation, bronchiectasis, bronchostenosis, and thoracoplasty failures. Tuberculous empyema associated with bronchial and cutaneous fistulas was present in a number of these patients. Oleothorax was established in only 13 patients who had no evidence of tuberculous pleural or bronchial disease. The oleothorax in these patients has been well tolerated. In 1 patient, an oleothorax was established in the presence of frank postresection tuberculous empyema in 1945. The patient did well and aspiration of a sample of oil in 1952 showed this to be clean and sterile on culture. The patient was lost to our observation, however, and died 5 years later of what was reported as a subphrenic abscess and tuberculous empyema. Detailed studies on this patient are not available at the present time.

In some of the patients with pulmonary tuberculosis thoracoplasty had been performed prior to pneumonectomy and in others the disease process had resulted in such marked contraction of the chest wall and elevation of

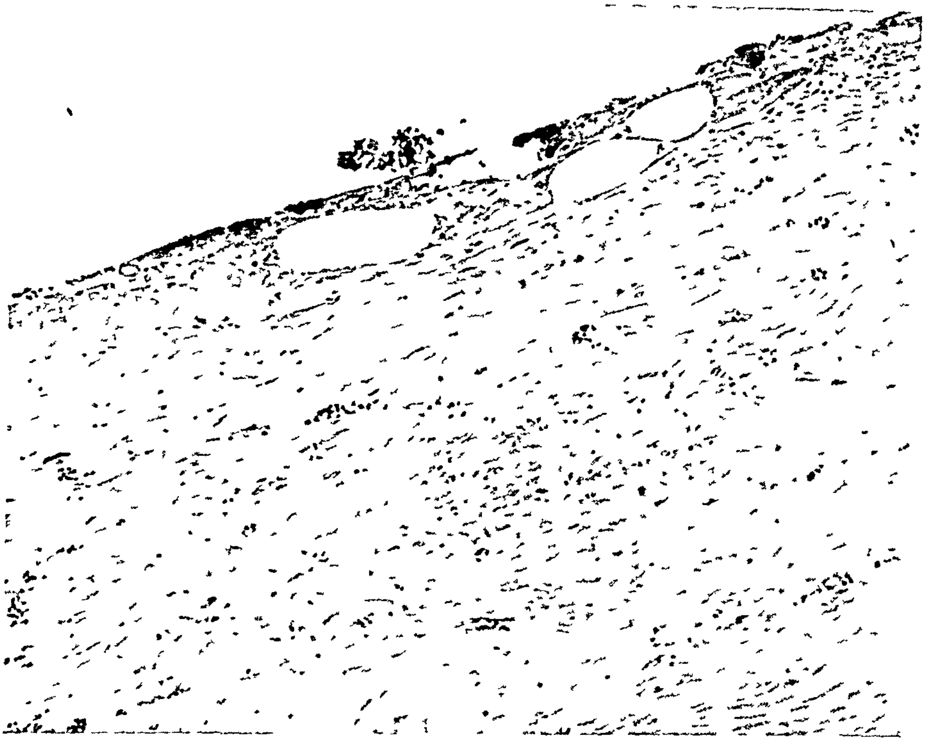

Fig 2.—Photomicrograph of parietal pleura of a patient who died of bronchogenic carcinoma 1 year following pneumonectomy and establishment of oleothorax. Oil-containing spaces are shown as well as clumps of malignant cells on the surface. The underlying fibrous membrane shows little inflammatory reaction.

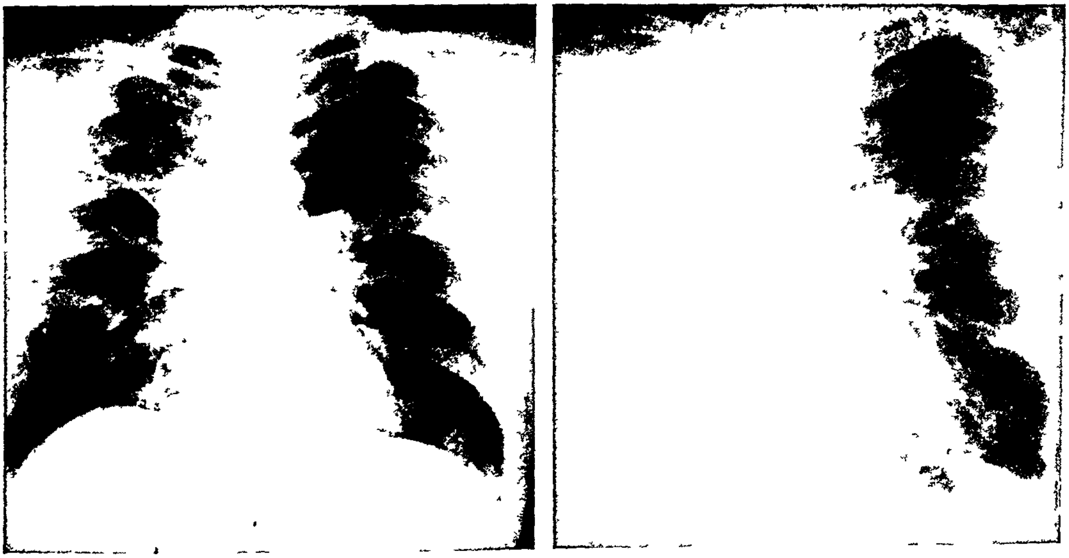

Fig 3.—Roentgenogram of patient prior to pneumonectomy for bronchogenic carcinoma of right upper lobe in 1949 and present film showing oleothorax with minimal mediastinal shift.

the diaphragm that a space filling prosthesis was unnecessary. In many of the patients with this disease thoracoplasty was used to obliterate the postpneumonectomy space because of involvement of the pleura or transected bronchus.

In the patients with bronchiectasis involving an entire lung and necessitating pneumonectomy, 5 patients had a markedly contracted thorax resulting in a small postpneumonectomy space. In the remaining 8 patients, oleothorax was established and maintained without difficulty. In 2 patients with adenomas involving the main bronchus and regional lymph nodes requiring a pneumonectomy, oleothorax was established for cosmetic reasons, both patients being women in the middle age group. Two patients with chronic pneumonitis of unknown etiology had oleothorax established, while in 1 patient with congenital cystic disease of the lung there was no associated contraction of the hemithorax on the right side. A large pleural space remained, requiring the instillation of 2,500 c.c. of oil.

Since thoracoplasty has not been used routinely in our clinic following pneumonectomy for bronchogenic carcinoma no data are available in determining the possible benefits of oleothorax over thoracoplasty in this disease, as far as function of the remaining lung is concerned. In a series of 11 patients pre- and postoperative pulmonary function studies indicated an average loss of 30 per cent in the maximum breathing capacity. However, since the preoperative function of the removed lung varied from normal to complete absence of function, such comparative studies are of little value. It has been our clinical impression that patients with oleothorax, particularly in the presence of extensive emphysematous changes in the remaining lung, have done quite well. In patients who have developed pleural and distant metastases following oleothorax, accumulation of fluid in the pleural space has been no problem. It appears that the presence of oil may inhibit the effusion secondary to pleural carcinoma involvement. In 1 patient with extensive carcinomatosis of the pleura found at pneumonectomy, radioactive gold was used on two separate occasions prior to the instillation of oil. This patient lived without evidence of reaccumulation of fluid or mediastinal shift for 1 year and died of distant metastasis.

DISCUSSION

Oleothorax as used in our clinic over a period of 10 years in patients undergoing pneumonectomy has proved of definite value in the control of the postresectional space. The oleothorax can be established with ease and when used with proper care and for definite indications is well tolerated. Difficulties were encountered only in instances of improper application such [illegible] its use in patients with infection of the pleural space in the presence [illegible] bronchial disease leading to fistula formation or inadequate sterilization [illegible] olive oil. Once the oleothorax has been established it req [illegible] attention, and patients followed for periods up to 10 [illegible] complications because of the presence of the oil. The mediastinum has been maintained in its original position and no thoracic deformity has resulted.

We are continuing the use of oleothorax in patients presenting a problem in the control of a large pleural postpneumonectomy space. Overdistention of the remaining lung, undesirable shift of the mediastinum, and elevation of the diaphragm is prevented by the application of this prosthesis without additional surgery and without thoracic deformity. Oleothorax should not be used in the presence of pleural infection, actual or potential bronchial and cutaneous fistulas, or in patients with residual carcinoma of the bronchial stump. In patients with prepneumonectomy contracted thorax, those with previous thoracoplasty, and in patients with small residual fluid-filled space and good position of the remaining lung, a slight shift of the mediastinum is well tolerated and an oleothorax is not necessary.

SUMMARY

1. Oleothorax was applied as a postpneumonectomy pleural space prosthesis in 149 patients.

2. When applied under proper conditions, sterile olive oil was well tolerated in all patients for periods up to 10 years.

3. Infection of the oleothorax occurred in 7 patients. In 4 of these the complication was secondary to the original disease, while in 2, and possibly 3, improper sterilization of the oil resulted in an immediate empyema.

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ESOPHAGOPERICARDIAL FISTULA OF BENIGN ORIGIN

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HYDROPNEUMOPERICARDIUM is a rare manifestation of disease. Shackelford,[1] in 1931, made a review of this entity and discussed the findings in 77 cases. Our attention was recently directed to the occurrence of hydropneumopericardium as a manifestation of benign esophagopericardial fistula. The development of such a fistula in an infant and the clinical problem which resulted seem worthy of reporting.

CASE REPORT

T. K. (V. U. H. #248643), an 11-month-old white male infant, was referred to the Vanderbilt University Hospital by his local physician for treatment of whooping cough. Past history from the mother revealed that the patient had enjoyed good health with normal growth and development until 5 weeks prior to admission when he developed fever and cough. This gradually developed into a paroxysmal cough which impressed the mother as being similar to the paroxysms of an older brother who had been diagnosed as having "whooping cough" 3 weeks previously. The patient also had episodes of vomiting with the paroxysms. Temperature at that time was 102° F., rectally, and little improvement was noted for the next few days. The patient had a generalized convulsive seizure 10 days prior to admission and was then examined by a local physician who made the diagnosis of pertussis and gave three injections of hyperimmune serum. Five days later the child was admitted to another hospital for treatment of progressive respiratory difficulty, cyanosis, and continuing fever. He was treated with oxygen, humidified air, and daily injections of antibiotics with a prompt fall in the fever to a normal range. His appetite improved and cough lessened but progressive respiratory difficulty continued. He was referred to the Vanderbilt University Hospital for further evaluation and treatment.

On admission the patient appeared acutely ill. Rectal temperature was 100.4° F., pulse 140 per minute, and respiratory rate 40 per minute. There was no cyanosis and peripheral veins were not dilated. Both lung fields were resonant with a few scattered harsh râles present bilaterally. The heart was normal, with no adventitious sounds. The liver was palpable one fingerbreadth below the right costal margin and the tip of the spleen was palpable. Blood pressure was recorded as 100/60 mm. Hg. There were no other significant findings.

Laboratory studies revealed that the urine was clear microscopically but contained two plus protein. Hemoglobin was 7.5 Gm. per 100 c.c. and the white blood count was 36,500 per cubic millimeter with 77 per cent neutrophils. Histoplasmin and tuberculosis skin tests were negative. Chemical determinations of the blood revealed carbon dioxide combining power 22.5 mEq./L., chloride 94.8 mEq./L., sodium 120 mEq./L., potassium 5.3 mEq./L., nonprotein nitrogen 24 mg. per cent, and serum protein 4.6 Gm. per cent with albumin-globulin ratio 2.7/1.9.

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Roentgenograms of the chest were interpreted as follows (Fig 1). "Films show an open safety pin undoubtedly lying in the esophagus with its point directed forward and upward. The point distinctly lies within the cardiac silhouette. There are also scattered densities throughout both lung fields suggesting the presence of considerable pneumonitis. There is broadening and mottling of the mediastinal shadow, possibly representing a mediastinitis."

The patient was placed in a Batson box and humidified oxygen was administered. Intravenous fluids were started and 50 c.c. of whole blood was given. Eight hours after admission esophagoscopy was carried out (G. M.) and a rusty open safety pin was removed by advancing the foreign body into the stomach, rotating, and then extracting the pin. No definite perforation could be demonstrated at that time. The patient tolerated the procedure well and after intradermal testing was given tetanus antitoxin.

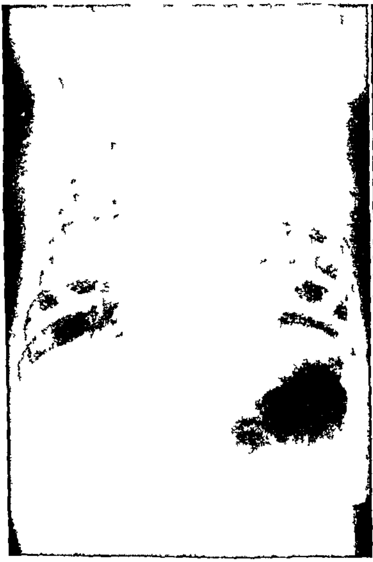

Fig 1

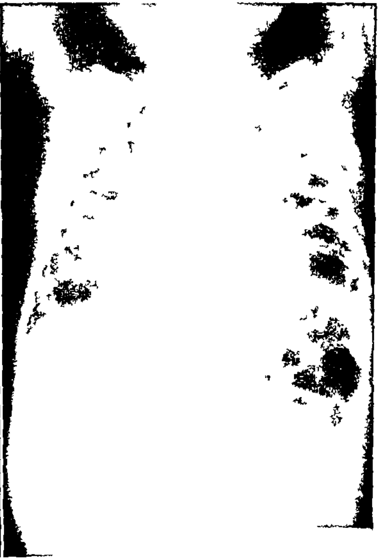

Fig 2

Fig 1.—Roentgenogram of the chest obtained on admission to the hospital showing open safety pin.

Fig 2.—Roentgenogram of the chest obtained on the fifth hospital day showing marked increase in the size of the cardiac shadow, air fluid level in the pericardial sac, and bilateral bronchopneumonia.

Cultures, reported on the second hospital day, grew out *Pseudomonas aeruginosa* from a throat swab and coliform organisms from blood. These organisms were sensitive to streptomycin and chloramphenicol and these drugs were started. Oral feedings were begun 2 days after extraction of the safety pin. The child made little improvement on treatment but no great change was noted until the fifth hospital day when he suddenly appeared moribund. Examination at this time revealed periorbital edema in spite of previous fluid restriction. The liver and spleen had each increased in size and some peripheral edema was noted. The heart sounds were muffled but no *bruit de moulin* was audible. An immediate chest roentgenogram revealed a marked increase in the size of the cardiac silhouette with an air-fluid level in the pericardium (Fig. 2). Venous pressure at this time was 340 mm. of saline. The electrocardiogram revealed low voltage and the neck veins were visibly distended.

The diagnosis of esophagopericardial fistula with cardiac tamponade was made and operation was carried out immediately. Using 0.5 per cent lidocaine hydrochloride infiltration anesthesia, a segment of the fifth costal cartilage was excised. The pericardium was exposed and incised releasing 100 to 150 c.c. of serosanguineous fluid with the distinct odor of Meade's 367, the infant's oral nutrient. Immediately on release of the air and fluid, the infant's color improved. He began to cry vigorously and to struggle on the table. The pericardium was sutured to the skin edges to ensure proper drainage by marsupialization.

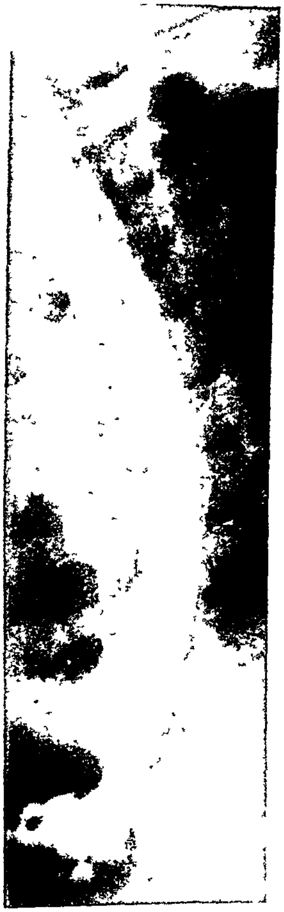

Fig. 3.—Esophagogram obtained by injecting Iodochloral on the sixth postoperative day which reveals a normal-appearing esophagus with no evidence of a functioning fistula.

The early postoperative period showed a remarkable improvement. The child remained alert and the temperature fell toward normal levels. The enlargement of the liver and spleen and the peripheral edema regressed. However, slight edema persisted and after 6 days a low-grade fever was still present. At this time the patient was digitalized with little improvement. Drainage from the pericardiostomy gradually ceased. Methylene blue was given by mouth as was Iodochloral without demonstrating a functioning fistula either visually or fluoroscopically (Fig. 3). Oral feedings were then started in small amounts and the patient maintained a slow improvement until the night of the tenth postoperative day when he again suddenly developed marked respiratory difficulty, air hunger, and abdominal distention. Roentgenogram of the chest revealed a normal sized heart but bilateral pleural effusion and a dense scattered bilateral pulmonary infiltrate. The patient deteriorated rapidly and died on the eleventh postoperative day.

Pertinent findings at necropsy were limited to the thoracic cavity. Approximately 10 c.c. of clear fluid was present in the right pleural cavity and the left pleural cavity was obliterated by adhesions. The mediastinal tissues were edematous and inflamed. Adhesions were present between the visceral and parietal pericardium. Two and one half centimeters above the esophagogastric junction on the anterior surface of the esophagus was a 1 mm. perforation through which a probe could be passed. The probe emerged through the parietal pericardium adjacent and posterior to the junction of the right auricle and inferior vena cava. On opening the heart there was a mural thrombus on the posterior aspect of the right ventricular wall. The thrombus was 0.5 by 0.5 cm. in size and on cut section its central portion was noted to be purulent.

The right lower lobe contained multiple elevated, hard, bluish nodules in the subpleural area. On cut section these areas were typical of multiple pulmonary infarcts and, in fact, some areas of infarction were undergoing suppuration. Microscopic sections supported the fact that these were mycotic emboli. Multiple areas of infarction were also scattered throughout the remainder of the right and left lungs. Cultures taken at the time of autopsy grew out *Pseudomonas aeruginosa* from the tracheobronchial tree and *Candida albicans* from the mural thrombus.

COMMENT

Hydropneumopericardium has been recognized as a clinical entity for over a hundred years. Shackelford[1] credited the first documented case to Bricheteau[2] in 1844. James,[3] in reviewing the same malady in 1904, found 38 cases of hydropneumopericardium and of these only 6 represented an esophagopericardial fistula of benign origin. According to James, Buist[4] described the first esophagopericardial fistula in 1838. We have been able to find 6 additional cases reported since James's review in 1904. The present case is apparently the thirteenth case to be reported (Table I). A recent article by McDaniel[5] referred to 11 cases of fistula secondary to benign conditions. However, the second case of Abbott[6] and that of Drouet[7] were omitted and the case of Chamber[8] was referred to as a benign ulcer when in fact it was secondary to an esophageal carcinoma.

The cases of esophagopericardial fistula arising secondary to neoplastic disease have not been included in Table I. We feel that an ulcerated, perforated neoplasm of the esophagus is probably beyond the bounds of curative resective surgery. The appalling fact is that all 13 patients suffering from benign esophagopericardial fistula have died. The diagnosis was made clinically in 8 cases, by necropsy in 4 and in 1 at the time of surgical intervention. Only 4 of the 8 cases diagnosed clinically were subjected to surgery with 4 postoperative deaths 22 hours, 3 days, 11 days and 14 days respectively. The over all mortality in the series is 100 per cent. This is a discouraging record in a benign condition which should be amenable to prompt surgical intervention and saving of the patient's life. The death of our patient was due actually to a complication of the initial myocardial perforation rather than the pericardial opening. All of the evidence before death indicated functional closure of the esophagopericardial fistula.

TABLE I. COLLECTED CASES OF ESOPHAGOPERICARDIAL FISTULA ARISING SECONDARY TO BENIGN CONDITIONS

AUTHOR	YEAR	AGE	CAUSE	PHYSICAL SIGNS	DIAGNOSIS	OUTCOME	AUTOPSY
1. Buist[1]	1838		Laceration esophagus from false teeth	None recognized	Autopsy	Died	Yes
2. Trotter[9]	1851	25 yr.	Perforated benign ulcer of esophagus	None recognized	Autopsy	Died	Yes
3. Walske[10]	1873		Perforation of esophagus from swallowing sword	Tympanitic precordium	Clinical	Died	Yes
4. Meigs[11]	1875		Perforated benign ulcer	Succussion splash	Clinical	Died	Yes
5. Huber[12]	1903		Erosion from lymph node	Tympanitic precordium	Clinical	Died	Yes
6. James[3]	1904		Perforated esophagus from ingested bone	Succussion splash, shifting dullness	Clinical	Died; 1 day postop.	Yes
7. Imperatori[13]	1928	13 mo.	Foreign body (safety pin) perforation	Bronchopneumonia	X-ray	Died	Yes
8. Abbott[6]	1945	6 days	Fistula following cauterization of web	Bronchopneumonia	Autopsy	Died	Yes
9. Abbott[6]	1945	46 yr.	Pulsion diverticulum; postop. emphysema	Succussion splash	Clinical	Died; 14 days postop.	Yes
10. Massias and Nguyen[14]	1948		Foreign body	Succussion splash	Clinical	Died	Yes
11. Drouet et al.[7]	1955	52 yr.	TBC abscess of mediastinum	Perforated esophagus	At exploration	Died; 3 days postop.	No
12. McDaniel and Knepper[5]	1956	60 yr.	Unknown	Succussion splash	Clinical	Died	Yes
13. Authors	1958	11 mo.	Foreign body (safety pin)	Cardiac tamponade	Clinical	Died; 11 days postop.	Yes

The physical findings of hydropneumopericardium are classical. The succussion splash or *bruit de moulin* synchronous with cardiac systole occurs with no other known condition. Cardiac tamponade which presented in our patient[8] has also occurred in 3 additional cases. The routine use of the roentgenogram should permit an earlier diagnosis before the physical findings of cardiac tamponade have developed. The demonstration of an air-fluid level in the pericardium establishes the diagnosis without question.

The possibility of this condition as a complication of ingested foreign bodies must be kept in mind and early surgical intervention is mandatory if esophagopericardial fistula is to be treated successfully. The condition of the patient will by necessity dictate a direct or indirect surgical approach. There can be no question that the procedure of choice would be a closure of the fistula with adequate toilet and drainage of the pericardium but marsupialization of the pericardium in an acutely ill, moribund patient could be lifesaving.

SUMMARY

1. A case of benign esophagopericardial fistula secondary to an ingested foreign body is reported.

2. A review of the literature reveals that 12 other cases of benign esophagopericardial fistula have been reported in the last century.

3. The mortality of this condition has been 100 per cent.

4. Although the diagnosis has been made clinically in 8 cases, only 4 have been subjected to surgical intervention.

5. Awareness of the possibility of this condition as a complication of ingested foreign bodies by pediatricians, endoscopists, radiologists, and surgeons and prompt surgical intervention offer the only hope for improvement in the survival rate.

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AN INVESTIGATION OF CARDIAC ARREST PRODUCED BY INJECTION OF POTASSIUM CITRATE INTO THE CORONARY CIRCULATION

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HEART-LUNG machines are now employed successfully in many centers and their use has permitted improvement in surgery for a number of different cardiac malformations. Optimum conditions for the correction of deformities within the heart will not be attained, however, until asystole can be induced. Although this is a radical concept, it is the conclusion of most investigators who have had experience with surgery in the open heart during perfusion of the body.

Melrose's preliminary communication on elective cardiac arrest induced by intra-aortic injection of potassium citrate solution[1] has been widely received. The majority of investigators in this field have tried the technique and it has been adopted for clinical use by several leading centers for cardiac surgery.[2, 3] Experience in our laboratory, however, aroused suspicion that this technique for asystole was the cause of serious myocardial damage. We therefore adopted this as an hypothesis and planned two series of experiments to test it. The present report summarizes the first series.

METHOD

Dogs of medium size were anesthetized with pentobarbital sodium given intravenously and ventilation was maintained through a large endotracheal tube. One hundred per cent oxygen was administered by a mechanical ventilator and soda lime was used for the absorption of carbon dioxide from the semiclosed system. The femoral artery and vein were cannulated for pressure measurements. A bilateral thoracotomy was made through the fourth intercostal spaces and the sternum was transected. In the groups of experiments in which the vena cavas were to be occluded, these vessels were isolated in the standard manner. The pericardium was opened widely in all animals and the aorta was dissected from the pulmonary trunk for a distance of 2 cm. above the origins of the coronary arteries. A plastic tube (6 mm., i.d., and 50 cm. long) was inserted into the left atrium via its appendage. The outer end of the tube was

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passed through the wall of the left chest and supported at a level of 15 cm. below the left atrium This tube provided the simplest system possible for rapid removal of aliquots from the left atrium

The first group of 5 experiments comprised one control series Two samples were withdrawn from the left atrial tube for determination of the serum potassium level immediately prior to the test conditions. No potassium citrate was injected but the vena cavas and aorta were occluded simultaneously, except in 1 experiment noted below. The pulmonary artery remained open as it did in all of the other groups Samples of blood were taken from the left atrium at intervals of 10 seconds during the 3 minutes of aortic and caval occlusion, and the concentration of serum potassium was determined in each sample. These 5 animals were allowed to recover and after approximately 30 minutes, were subjected to the experiment outlined for Group 3.

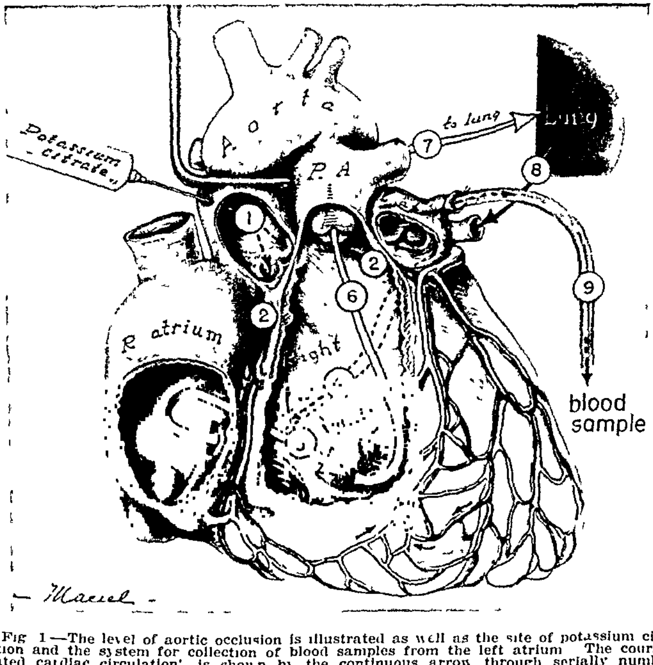

Fig 1—The level of aortic occlusion is illustrated as well as the site of potassium citrate injection and the system for collection of blood samples from the left atrium The course of "isolated cardiac circulation' is shown by the continuous arrow through serially numbered locations Emphasis is laid on the recirculation of blood from the coronary sinus through the lungs and back into the chambers of the left side of the heart

The second group of experiments included 10 animals. Two control samples were withdrawn from the left atrium and immediately after this potassium citrate solution (2 c.c. of 25 per cent solution with 18 c.c of arterial blood) was injected into the occluded aorta so as to perfuse the coronary arteries. The dose of potassium citrate was the amount required to arrest the heart. The vena cavas were not occluded in this series. Ten blood samples for serum potassium determinations were drained from the left atrium *after* cardiac arrest. The interval between samples was approximately 10 seconds.

The third group comprised 11 dogs in which potassium citrate in the same dilution was injected into the occluded aorta. Again, the amount injected was just enough to cause asystole. In this group, however, the vena cavas were occluded simultaneously with the aortic occlusion. Sampling from the left atrium was identical in technique to that of the previous group.

The last group, consisting of 4 animals, was an additional control series. The aorta and vena cavas were occluded and asystole was produced by injection of acetylcholine (100 mg. in 10 c.c. of physiologic saline) into the occluded aorta. Samples were taken from the left atrium using the same technique employed in the preceding groups.

Fig. 1 illustrates the course of the circulation through the heart and lungs and the site from which blood samples were drawn after occlusion of the aorta.

The analysis of serum samples for potassium content was completed without delay, using the Janke flame photometer. The variation in duplicate samples did not exceed 0.1 mEq./L.

RESULTS

In the groups of experiments in which potassium citrate was injected and in both groups of controls, the heart continued to contract effectively for 10 seconds or longer after the aorta was clamped. During this brief period of isolated cardiac circulation the effluent from the myocardium was forced through the lungs again by the right ventricle. This blood flowed into the left atrium and ventricle, was pumped out once more and forced by the aortic obstruction to re-enter the coronary circuit. This may be clarified by reference to Fig. 1 where an arrow connects the anatomic sites, labeled seriatim.

The levels of potassium observed in the first group of controls are given in Table I. A significant elevation of potassium contents was observed in only 2 dogs, 17 and 19. The former may illustrate chemical confirmation of a clinical impression. This animal had the aorta closed by accident 20 seconds prior to interruption of caval flow, causing the heart to become greatly distended. The tone of the myocardium never returned to normal and when, a short time later, the heart was arrested with potassium citrate, it continued to lose potassium as shown in Table III. We suspect that acute cardiac dilatation of this type results in cellular damage and this, as has been shown by Harris[4] is reflected in elevation of the potassium content of coronary venous blood. The remaining experiments in this control series indicate that, in a short period of combined aortic and caval occlusion, there is no significant change in the potassium content of blood collected from the left atrium.

In the second group of animals in which potassium citrate was injected into the occluded aorta, and the vena cavas were not occluded, a relatively large flow continued through the right heart until asystole developed. The results from

TABLE I. POTASSIUM CONCENTRATION IN SERIAL SAMPLES FROM LEFT ATRIUM DURING 3 MINUTE OCCLUSION OF VENA CAVAS AND AORTA WITHOUT INJECTION OF POTASSIUM CITRATE

DOG NO.	CONTROL LEVEL K IN LEFT ATRIAL BLOOD (mEq./L.)	PEAK LEVEL K IN LEFT ATRIAL SAMPLES (mEq./L.)
17	4.7	7.4
19	3.6	4.0
20	4.3	4.5
21	5.4	5.5
22	3.8	3.6

this group are listed in Table II. Most of the hearts contracted 14 to 25 times after the start of the potassium citrate injection. Blood withdrawn from the left atrium after asystole was induced showed peak levels of potassium in the range of 10 to 30 mEq./L. in the majority of animals. A comparison between the total dose of potassium administered and the total amount recovered in drainage from the left atrium must be made cautiously, because calculation of the latter value is subject to error of varying degree. It is certain, however, that in 2 of the group, Dogs 6 and 7, the potassium recovered from the left atrium was in excess of the dose administered. This, in the light of the work of Harris and Hamilton and their colleagues,[4, 5] may indicate myocardial damage.

TABLE II. POTASSIUM IN SERIAL SAMPLES FROM LEFT ATRIUM FOLLOWING AORTIC OCCLUSION AND ARREST WITH INJECTION OF POTASSIUM CITRATE
(PULMONARY ARTERY AND VENA CAVAS NOT OCCLUDED)

DOG NO.	NO. HEARTBEATS FROM START OF INJECTION TO ARREST	CONTROL LEVEL K LEFT ATRIUM (mEq./L.)	PEAK LEVEL K LEFT ATRIUM (mEq./L.)	TOTAL DOSE K (mEq./L.)	TOTAL K RECOVERED (mEq./L.)
1	10	4.6	9.8	1.15	0.53
2	14	3.8	20.5	1.38	1.03
3	60	4.7	26.0	3.68	1.80
4	6	4.3	5.9	0.92	1.0
5	22	2.9	8.3	1.84	0.59
6	20	3.9	31.0	1.84	2.50
7	22	2.4	35.0	2.53	3.60
8	25	3.8	9.5	1.61	0.56
9	14	3.5	11.7	1.38	0.59
10	6	2.5	10.6	0.92	0.46

Table III summarizes data from Group 3, the animals with occlusion of the vena cavas and the aorta and injection of potassium citrate. In these experiments the only flow through the right heart was the volume from the coronary sinus. The conditions of this experiment consequently resembled closely the technique employed for potassium citrate asystole in clinical practice. The ventricles continued with 10 to 20 contractions in the majority of experiments after the start of the potassium citrate injection. The peak levels of potassium in left atrial samples drawn after arrest exceeded 30 mEq./L. in over half the animals. Experiments in 4 dogs, 11, 12, 18, and 19, demonstrated a notable excess of potassium in blood collected from the left atrium above the amount injected into the coronary circuit. Dog No. 17 is not grouped with these 4 because of the change noted in the control period and mentioned in discussion of Table I.

TABLE III. POTASSIUM IN SERIAL SAMPLES FROM LEFT ATRIUM FOLLOWING OCCLUSION OF VENA CAVAS AND AORTA AND ARREST WITH INJECTION OF POTASSIUM CITRATE (PULMONARY ARTERY NOT OCCLUDED)

DOG NO.	NO. HEARTBEATS FROM START OF INJECTION TO ARREST	CONTROL LEVEL K LEFT ATRIUM (mEq./L.)	PEAK LEVEL K LEFT ATRIUM (mEq./L.)	TOTAL DOSE K (mEq./L.)	TOTAL K RECOVERED (mEq./L.)
11	--	3.5	90.0	1.84	2.4
12	10	4.0	49.0	1.38	1.85
13	9	4.3	36.0	1.15	0.86
14	9	5.6	31.5	2.30	---
15	25	5.6	9.1	7.36	3.6
16	50	4.9	21.2	1.84	0.80
17	--	5.0	47.0	2.99	5.12
18	29	4.0	113.0	3.45	4.76
19	13	3.4	61.0	2.07	3.10
20	--	4.5	22.0	3.22	1.67
22	20	3.6	18.1	4.3	2.5

The highest levels of potassium for the individual experiments of Group 4 (aortic and vena caval occlusion and asystole produced by acetylcholine) are given in Table IV. The peak values of potassium were slightly higher than the control values. This change was in the range observed in the first control series where left atrial samples were taken during aortic and caval occlusion without asystole.

TABLE IV. POTASSIUM IN SERIAL SAMPLES FROM LEFT ATRIUM FOLLOWING OCCLUSION OF VENA CAVAS AND AORTA AND ARREST WITH INJECTION OF ACETYLCHOLINE

DOG NO.	CONTROL LEVEL K LEFT ATRIUM (mEq./L.)	PEAK LEVEL K LEFT ATRIUM (mEq./L.)
23	3.9	4.2
24	3.0	3.5
25	4.5	4.8
26	3.7	3.5

DISCUSSION

This study is concerned primarily with the potassium content of blood in the left heart or entering it from the pulmonary circuit after asystole induced by the injection of potassium citrate into the coronary circulation. The relatively concentrated injectate perfuses the coronary system but ventricular contractions continue long enough to force the coronary sinus effluent back into the pulmonary circulation. The method of this experiment permits sampling of blood draining from the pulmonary venous system into the left atrium. Experiments of Groups 1 and 4 indicate that during the short period of observation after occlusion of the aorta and vena cavas the potassium content of blood in the pulmonary vessels and left atrium rose 0.5 mEq./L. or less. Experiments of Groups 2 and 3 revealed a relatively high concentration of potassium to which the left heart is exposed when asystole is induced by the Melrose method. We suspect that these high levels of blood potassium may be correlated with complications encountered in the left ventricle after use of this technique. In a significant number of the dogs in Groups 2 and 3, there was loss of potassium from the myocardium into the coronary venous blood and this strongly suggests that there was acute injury to the heart.

SUMMARY

1. Experiments were done in which the level of potassium was measured in blood samples drawn from the left atrium. The potassium rose very slightly in a simple control group in which asystole was not induced. A similar slight rise was observed in another control group in which asystole was produced by acetylcholine.

2. Two groups of animals were studied in which the heart was arrested by potassium citrate and blood samples were taken from the left atrium. High concentrations of potassium were found in blood samples from this chamber.

3. Some of the animals subjected to potassium citrate asystole lost additional amounts of potassium from the myocardium.

The authors gratefully acknowledge the technical assistance of Mr. T. Payne, Mrs. T. Wiehe, and Mrs. B. Doherty. All potassium determinations were made by Mr. N. Keller.

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THE LOCAL EFFECT OF POTASSIUM CITRATE SOLUTION IN ATRIAL POUCHES OF DOGS

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The Melrose technique for cardiac arrest has been adopted with very little delay by several outstanding surgical centers.[1, 2, 3] When it is tried in the laboratory and the animal's life is maintained by total body perfusion, it appears to be entirely reliable for the induction and maintenance of asystole. However, the rate of long-term survival after cardiac arrest by potassium citrate during total perfusion in dogs is stated only infrequently, and may be relatively low.[4]

Our own experience with the method has caused us to suspect that myocardial injury may result from its use. An earlier series of experiments demonstrated that the left atrium and ventricle are often exposed to very high concentrations of potassium when the injection is made into the occluded aorta in the usual way.[5] It is possible that pooling of potassium-rich blood in the left heart chambers is related to the abnormal tonic type of contraction of the left ventricle that has occasionally been observed following arrest of the dog's heart with potassium.[6] We questioned whether the high concentration of potassium within the cardiac chambers could be harmful to the endocardium and subjacent muscle, and planned a simple experiment to explore this possibility. The present report summarizes the experiment, the second in a series of two planned to test the hypothesis that use of the Melrose technique is the cause of myocardial damage in dogs.

METHOD

Mongrel dogs were employed and only those with signs of distemper were considered unsuitable for the experiment. The methods for anesthesia and ventilation were the usual ones used in this laboratory and described in an earlier report.[5] The blood pressure was observed by means of a mercury manometer attached to the femoral artery. Both pleural spaces were opened through short incisions between the fourth and fifth ribs. The pericardium was opened through two incisions, each one parallel with and ventral to the

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phrenic nerve on the corresponding side The atrial appendages were easily lifted into the pericardial incisions and small forceps with atraumatic blades were applied so as to occlude them at their bases as illustrated in Fig 1 Occlusion of the atrial appendage on one side served as a control on the factor of trauma The clamped appendage on the other side served as the experimental pouch Blood was withdrawn from the isolated pouch with a small needle and replaced with a solution of potassium citrate Leakage from the puncture site was prevented by a fine silk mattress suture

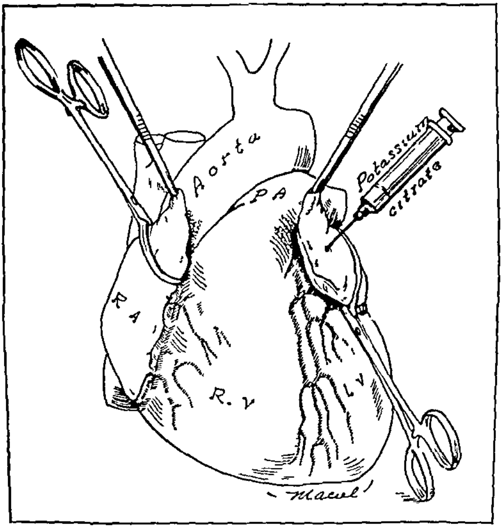

Fig 1 —The appendage of each atrium was elevated and occluded at its base with an atraumatic clamp In the experiment illustrated the empty left appendage was filled with potassium citrate solution The right appendage was subjected to the same surgical trauma and served as a control

The 16 animals in the experiment were divided into two groups The first included only 5 dogs and in these the experimental atrial pouch was filled with 25 per cent solution of potassium citrate The volume required varied from 1 5 to 4 0 c c and overdistention was avoided Thus, in this group, the total amount of potassium administered was similar to that employed clinically but the solution was much more concentrated since it was not mixed with blood

The second group of 11 dogs received potassium citrate in a more dilute form In a previous study we found that with the Melrose technique the concentration of potassium in blood recovered from the left atrium averaged 30 mEq /L[5] In this group, therefore, the atrial pouch on the experimental side was filled with potassium citrate solution in concentration of 30 mEq /L

The forceps remained in position for 30 minutes and then the appendages were released and allowed to retract into the pericardium. The potassium citrate was allowed to escape into the atrium at the conclusion of the first few experiments. This was invariably associated with serious arrythmias and, therefore, in all subsequent experiments, the chemical was aspirated from the appendage at the end of 30 minutes before removal of the atraumatic clamp. The appendages were removed later for microscopic examination and the pathologist (P. J. W.) was not informed which one was the experimental and which one was the control pouch. Animals that did not recover fully from the procedure were included in the study; the time interval between potassium instillation and death is given in Tables I and II. All survivors were sacrificed on the third day after the experiment.

RESULTS AND DISCUSSION

Table I summarizes the findings in the group of dogs injected with the more concentrated solution of potassium citrate. Four out of 5 showed myocardial necrosis in the experimental pouch and none in the control appendage. This change was present in every animal that survived 24 hours or longer after instillation of the chemical. It is shown in Fig. 2 which is a photomicrograph of the experimental pouch from Dog 401 in this series. Epicarditis and interstitial hemorrhage were the only changes observed in the appendages that served as controls. The characteristic histologic picture of the myocardium in control pouches is shown in Fig. 3.

TABLE I. RESULTS IN ANIMALS IN WHICH 25 PER CENT SOLUTION OF POTASSIUM CITRATE WAS INJECTED

DOG NO.	SURVIVAL (HR.)	ATRIAL POUCH WITH POTASSIUM CITRATE	CONTROL ATRIAL POUCH
389	72	Severe and extensive necrosis of myocardium	Normal except for area of acute epicarditis
401	24	Severe myocarditis with scattered areas of necrosis	Normal
403	72	Extensive myocardial necrosis with interstitial hemorrhage	Normal
405	1	Normal	Myocardium normal; extensive interstitial hemorrhage
407	40	Widespread myocarditis with areas of necrosis	Normal except for mild epicarditis

Table II lists the pathologic changes in the atrial pouches injected with the dilute solution of potassium citrate. Six dogs (416, 417, 420, 421, 423, 441) out of 11 in this group had necrosis in the experimental pouch whereas this change was not found in the control pouch of any animal in the series. Figs. 4 and 5 are photomicrographs of the experimental and control pouches, respectively, from Dog 441. In 2 additional dogs (412, 413) the inflammatory reaction in the epicardium, myocardium, and endocardium was more severe in the experimental pouch than in the control. Three dogs (426, 434, 435) showed changes in the control pouches as severe as those seen in the experimental side. It was difficult, if not impossible, to determine if epicardial reaction extended into the wall of a structure as thin as the atrial appendage but

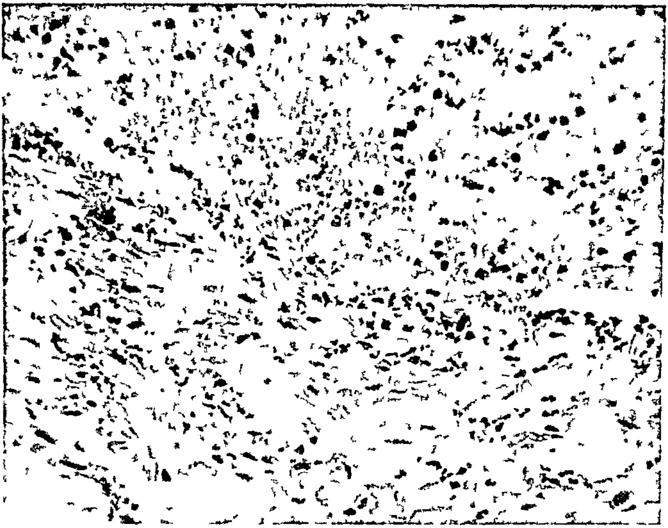

Fig 2—Photomicrograph from atrial pouch exposed to potassium citrate solution (25 per cent) and removed 24 hours later (Dog 401) There is severe myocarditis with areas of necrosis

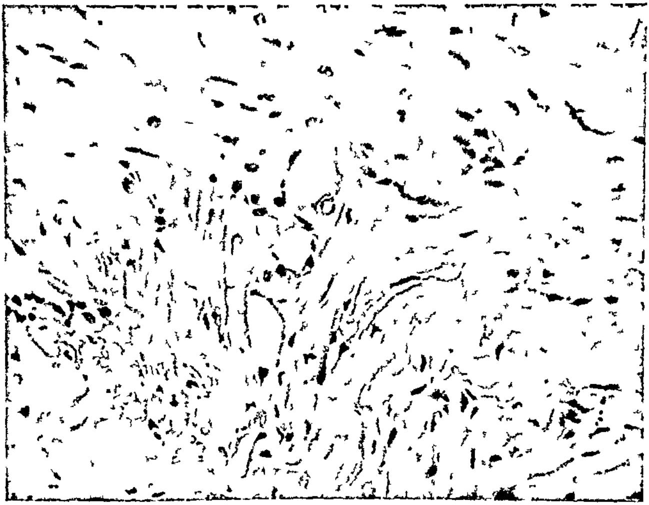

Fig 3—Photomicrograph from control atrial pouch removed 24 [illegible] it
401) The histologic picture is [illegible]

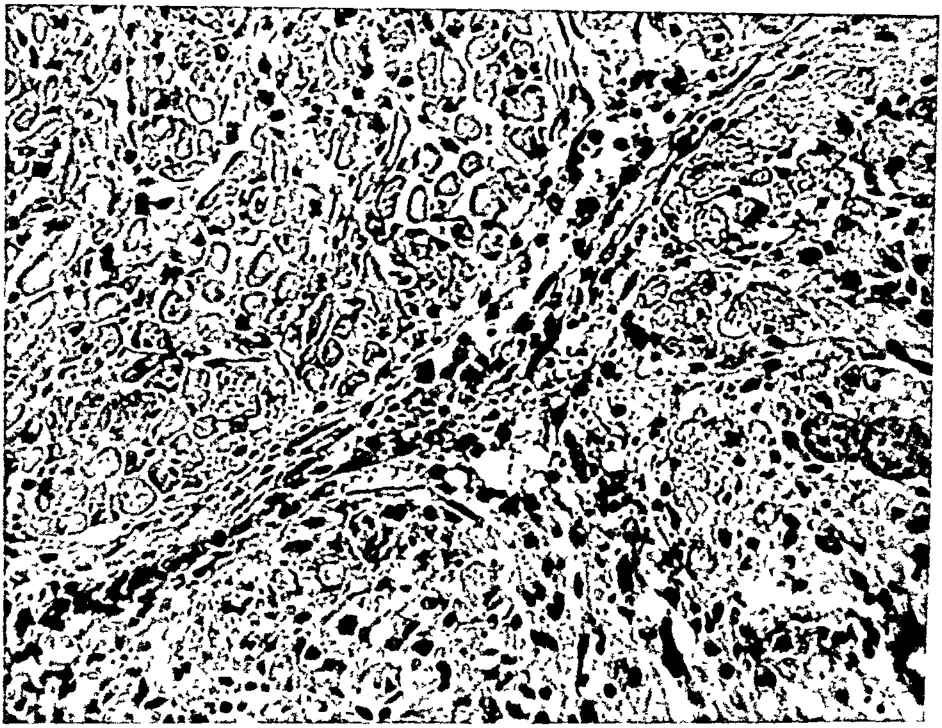

Fig. 4.—Photomicrograph from atrial pouch exposed to potassium citrate solution (30 mEq./L.) and removed 72 hours later (Dog 441). Widespread inflammation is shown and some necrosis of the myocardium.

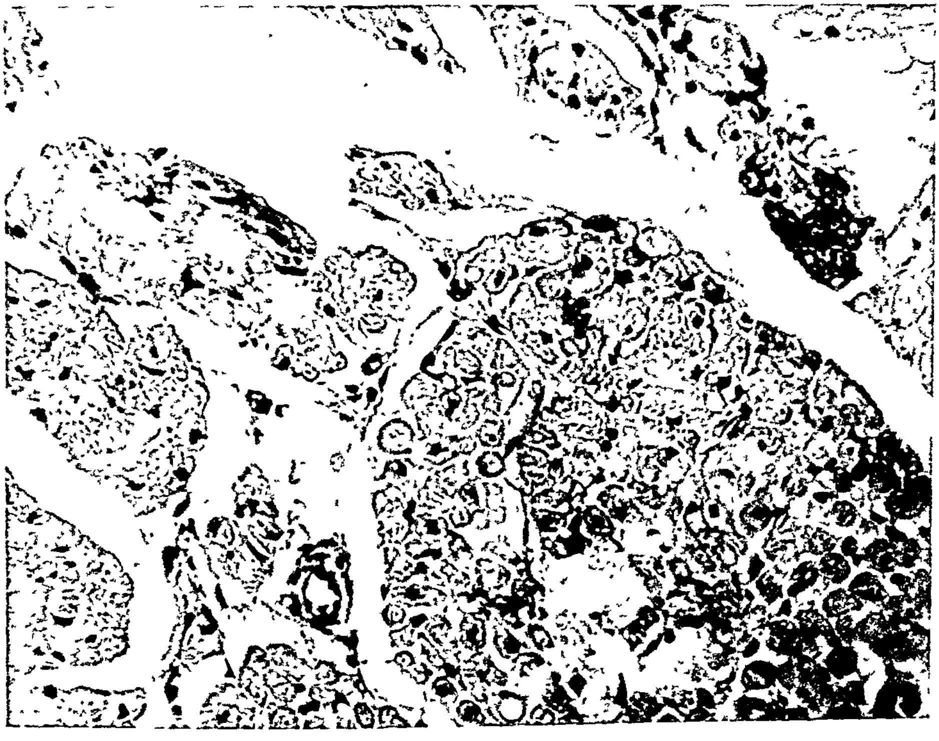

Fig. 5.—Photomicrograph from control atrial pouch removed 72 hours after experiment (Dog 441). There is slight epicarditis.

the changes were described as progressing this way in 3 experiments (423, 434, 435). Inward extension of epicardial reaction would be more likely to result from trauma and infection than from the chemical agent instilled into the endocardium but it was impossible to clarify this point by these experiments.

TABLE II RESULTS IN ANIMALS IN WHICH DILUTE SOLUTION OF POTASSIUM CITRATE WAS INJECTED

DOG NO	SURVIVAL (HR.)	ATRIAL POUCH WITH POTASSIUM CITRATE	CONTROL ATRIAL POUCH
412	*48*	*Epicarditis and small focus of myocarditis and endocarditis*	*Epicarditis*
413	72	Epicarditis and focal myocarditis and endocarditis	Epicarditis
416	48	Epicarditis and focus of myocardial necrosis	Epicarditis
417	24	Epicarditis and foci of myocardial necrosis	Epicarditis
420	24	Epicarditis, necrosis, hemorrhage and inflammation of myocardium	Epicarditis
421	24	Epicarditis with diffuse myocarditis and patchy necrosis	Epicarditis
423	72	Epicarditis, patchy endocarditis and myocardial necrosis	Epicarditis with some extension into myocardium
426	24	Epicarditis and focal myocarditis	Epicarditis and focal myocarditis
434	24	Epicarditis extending into myocardium	Epicarditis extending into myocardium
435	72	Severe patchy epicarditis extending into myocardium	Epicarditis, focal myocarditis, and endocarditis
441	72	Epicarditis, endocarditis, and myocardial necrosis	Slight epicarditis

These findings suggest that serious injury to the dog's heart may occur when it is exposed to concentrations of potassium citrate used in the Melrose technique In this experiment, factors of injury to the atrium from manipulation and infection were the same in the control side as in the atrium exposed to the potassium salt Therefore, we suspect that the myocardial injury was due to direct effect of potassium citrate upon the heart muscle

SUMMARY

1 A description is given of an experiment in dogs in which both atrial appendages *were isolated for a short period One appendage was used* as a control while the other served as a closed pouch which was filled with potassium citrate solution for 30 minutes The appendages were removed after varying intervals and examined microscopically.

2 Concentrated potassium citrate solution (25 per cent) caused myocardial necrosis in all 4 dogs that survived 24 hours or longer

3 Dilute potassium citrate solution (30 mEq./L.) caused a more severe myocardial reaction than was found on the control side in 8 out of 11 animals The 8 included 6 dogs with necrosis in the experimental pouch and 2 others with inflammatory reaction more severe than that found in the corresponding controls

The authors are indebted to Mrs. T. Wiehe for her technical assistance with these experiments.

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SINUSAL STANDSTILL WITH VENTRICULAR AUTOMATISM DURING RETROGRADE PERFUSION OF THE CORONARY SINUS UNDER HYPOTHERMIA FOR DIRECT SURGICAL APPROACH TO THE AORTIC VALVES

An Experimental Study

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Direct surgical approach to the aortic valves necessarily requires the uncovering of the aortic orifices of the coronary arteries. Therefore we are faced with two fundamental difficulties: (1) the interruption of the coronary flow, and (2) the danger of coronary air embolism. In order to overcome these obstacles, employing the cardiopulmonary bypass technique at normal temperature, Lillehei and co-workers[1,2] employed coronary perfusion during the intervention. At first this perfusion was effected through a direct cannulation of the aortic orifices of the coronary arteries; later on, the same authors preferred to use the retrograde coronary sinus perfusion. This technique enabled the surgeon to work directly on the aortic valves with safety since the aortic orifices of the coronary arteries become temporarily transformed from arterial routes into venous routes. Almost at the same time, Blanco and his colleagues[3] developed a similar technique.

While the cardiopulmonary bypass, with the body at normal temperature, leaves the heart unharmed, the simultaneous use of the retrograde perfusion of the coronary circle can bring about several types of disorders of the heart rhythm, sometimes even ventricular fibrillation as one deducts from the original article by Lillehei and from personal communication of Bailey.[4] Their interpretation seems to us unconvincing.

As a variation of the above-mentioned technique (retrograde coronary sinus perfusion with bypass at normal temperature), we have performed a retrograde perfusion of the coronary sinus under hypothermic condition with a technique already described by us in a preceding paper.[5]

In this short article we wish to illustrate an unusual disorder of the heart rhythm, which has constantly presented itself in all the experiments performed with the above-mentioned method. It is an arrhythmia which appears generally after 15 seconds to 40 seconds from the start of the inversion of the coronary circle; a sinusal bradycardia takes place and quickly increases until a complete stoppage of the atrioventricular activity is reached. Later on,

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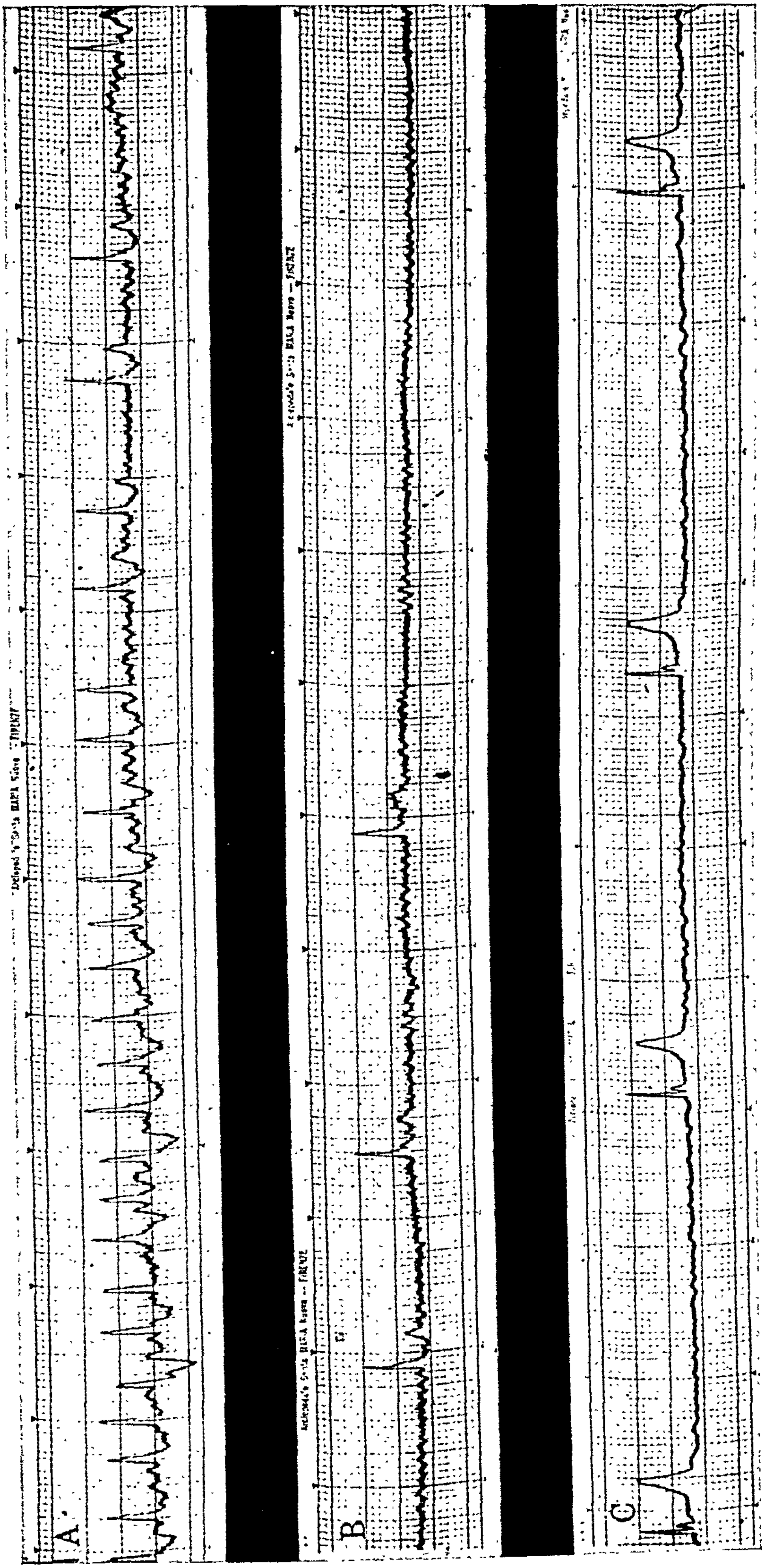

Fig. 1.—This electrocardiogram is from a patient who did not have sinusal standstill. Before the beginning of the retrograde coronary perfusion, an atrial fibrillation takes place with ventricular frequency of 180 systoles per minute (*A*). *B* shows the atrioventricular dissociation reached 15 seconds after the start of the retrograde coronary perfusion. The auricles continue to *fibrillate* while the *frequency* of the ventricles is 10 systoles per minute (as shown better in *C*).

an idioventricular center emerges which controls the ventricles with a regular frequency of 10 to 15 systoles per minute, while the auricles are in complete arrest Sometimes this center can be disturbed by the presence of some ventricular extrasystoles When the retrograde perfusion has ended and the normal coronary circulation has begun, the disturbance ceases and the sinusal rhythm starts again

In some cases in which, during the preperfusional phase, owing to the sinus cannulation, the auricles had begun to fibrillate and the ventricular frequency had risen to 140 to 180 systoles per minute, the beginning of the coronary retrograde perfusion caused the sudden dissociation of the atrial activity from that of the ventricle In fact, while the auricles continued to fibrillate, the ventricles were controlled on the low frequency which we have already mentioned (Fig 1)

The meaning of this phenomena goes beyond our scope We would like to mention that similar facts have been observed, either by employing some cardioplegic drugs (in particular, acetylcholine[6]), or by producing coronary ischemia by placing a clamp on the ascending aorta which will block the coronary orifices[7]

It should be noted that, when the described technique has been used and ventricular fibrillation has appeared, it was observed only several minutes after the retrograde coronary perfusion had been interrupted and after the systemic circulation had been put into action again

SUMMARY

A peculiar disorder of the heart rhythm is described which appears during the retrograde coronary sinus perfusion performed for direct surgical approach to the aortic valves under hypothermic conditions

This arrhythmia is represented by sinusal arrest taking place 10 to 15 seconds after the start of retrograde coronary perfusion, while the ventricles are controlled by an idioventricular center, which was also present in those cases in which an atrial fibrillation was taking place

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AN OCULAR SIGN USEFUL FOR EXPERIMENTAL SURGERY WITH PUMP-OXYGENATOR

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Authors in general agree on the possibility of acute lesions in the central nervous system during perfusion with a pump-oxygenator. In bypassing the heart and lung in the experimental laboratory, we routinely found an accurate sign of central nervous system lesions, which also proved to be of prognostic value. This sign was described in a previous paper[1] and further observations have confirmed this data. We believe this sign may be of interest to those working in the techniques of extracorporeal circulation. In the literature at hand we were unable to find any reference of this sign. For easier understanding we will present the behavior of the nictitant membrane (N.M.) and other ocular reflexes in the normal and conscious dog.

The conscious dog shows (a) very strong periorbital, palpebral, and conjunctival reflexes (the first of these has a large reflexological area and the most sensitive part is that near the internal ocular angle); and (b) the nictitant membrane (N.M.) is completely retracted over the internal ocular angle and is practically invisible, except for its pigmented free end. (Fig. 1, *A* and Table I.)

In the anesthetized dog under deep anesthesia (a) the N.M. is completely relaxed and covers a large surface of the ocular globe; this, together with convergent strabismus, causes the cornea and iris to be invisible; (b) the periorbital, palpebral and conjunctival reflexes are absent; and (c) the eyelids are closed (Fig. 1, *B*).

Under light anesthesia (a) the N.M. begins retraction and the end of the cornea is shown; periorbital and palpebral reflexes appear now, and will be stronger *even before* the N.M. is completely retracted (this is an important observation); and (b) the eyelids are still closed (Fig. 1, *C* and *D*).

In the almost awake dog (a) the N.M. is partially relaxed (more than 75 per cent of the cornea is seen); (b) very strong periorbital and palpebral reflexes are present (very slight friction produces blinking); and (c) the eyelids are closed (Fig. 1, *E*).

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TABLE I

PALPEBRAL AND PERIORBITAL REFLEXES	N.M.	EYELIDS	MEANING
Positive	Totally retracted	Open	Awake
Negative	Totally relaxed	Closed	Deep anesthesia
Positive	Partially relaxed	Closed	Light anesthesia
Negative	Totally retracted	Open	Lesion in central nervous system

A pathologic sign, but a reversible one if its cause is rapidly attacked (prolonged hypotension, anoxic anoxia, microembolism, etc.), is that during the deep plane of anesthesia, as well as during light anesthesia (a) the N.M. begins quick retraction to the internal ocular angle; movement might frequently go on and finish retraction in a few seconds (when lesion is serious); (b) there is absolute lack of periorbital and palpebral reflexes even if the N.M. has completely disappeared from the ocular field; corneal reflex is also missing; if anesthesia has been lightened before the accident, periorbital and palpebral reflexes disappear; and (c) the eyes are open and the animal seems to look but, of course, without seeing (Fig. 1, *F*).

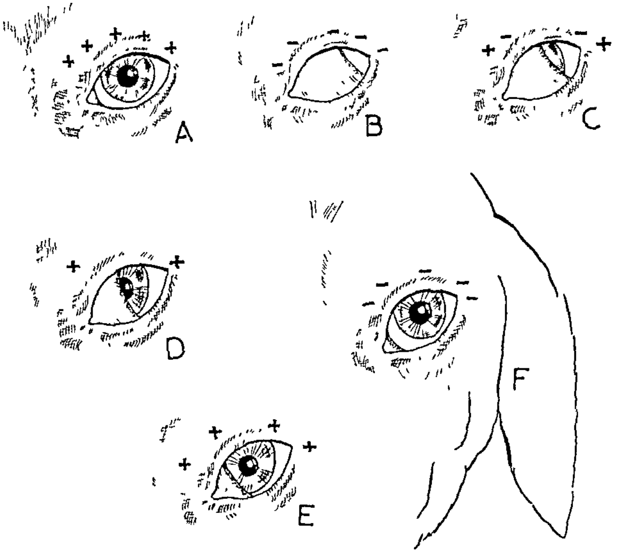

Fig. 1.

If, upon noticing that the N.M. is retracting, the trouble is localized and solved (as has happened to us on many occasions when the pump-oxygenator operator and the surgeon were notified) the N.M. spontaneously relaxes again and it returns to the position it had before. Under these conditions the dog will behave as a normal animal.

In all normal cases as described above, perfect recovery of the dog is assured. It will awake, answer a call, perform coordinate voluntary movements, walk, and even eat. In the pathologic cases as described above, the dog will not awake. It will recover spontaneous breathing, arterial pressure will keep within acceptable levels, and it will even survive for several hours but it will actually be in a coma, similar to that produced by very deep anesthesia, but with a retracted N.M. and open eyes. It will feel no pain, perform no voluntary movement, and death will occur from respiratory or circulatory arrest.

SUMMARY

An ocular sign of prognostic value is described which has been observed in dogs during experimental cardiac surgery using a pump-oxygenator.

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COMPLETE DRAINAGE OF PULMONARY VEINS INTO THE CORONARY SINUS—LEFT SUPERIOR VENA CAVA COMPLEX

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ANOMALOUS insertion of all pulmonary veins into various components of the systemic venous system are being reported with increasing frequency Surgical treatment has proved to be possible in some patients To the list of operable variations of the basic abnormality we would add the situation encountered in a recently studied patient

CASE REPORT

V B, a 6 year old girl, was found to have a cardiac murmur at the age of 2½ years From the early months of life the parents had noted prominence of the left chest She had always become fatigued and short of breath after brief exertion Profuse perspiration was a feature even in cool weather There had been no cyanosis, chest pain, syncope, cough, or signs of cardiac failure

On physical examination the child was underdeveloped and undernourished There was no cyanosis There were no abnormal pulsations of the cervical vessels and the trachea was in the midline The bony thorax was asymmetrical, the left anterior chest being more prominent than the right The sternum was protuberant The lungs were clear The heart was not enlarged to percussion There was no thrill The cardiac rate was 96 per minute and there was a normal sinus rhythm The second sound at the base to the left of the sternum was accentuated 1 plus A short, harsh systolic murmur an[illegible] an early diastolic blow were heard over the left thorax, best in the third interspace n[illegible] the sternal border The systolic murmur could also be heard over the right chest [illegible]e liver was not enlarged Peripheral pulses were full The height was 46 inches, w[illegible]ht 41 pounds, blood pressure, 90/50 mm Hg

Laboratory data There were 13 5 grams of hemoglobin The hematocrit [illegible]as 41 per cent The electrocardiogram (Fig 1) showed right ventricular hypertro[illegible] O[illegible] films and fluoroscopy the pulmonary vascular markings were accentuated 2 [illegible]us Th[illegible] main pulmonary artery was not clearly defined but was considered to be d[illegible]ted Th[illegible] heart was enlarged 2 plus, with rounding of the left border (Fig 2) The right [illegible] segment was somewhat prominent In the right anterior oblique view there wa[illegible] anterior prominence and in the left anterior oblique, 1 plus anterior and 1 plus p[illegible] prominence

The data secured on cardiac catheterization are shown in Table I, [illegible] catheter was introduced into a left antecubital vein, it passed via a per[illegible] perior vena cava to the right atrium and right ventricle Re introduced thr[illegible] arm vein, it passed through a right superior vena cava to right atrium, [illegible] pulmonary artery, and coronary sinus There wa[illegible] a marked step up in ox[illegible]

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the coronary sinus. This persisted through the right heart and pulmonary artery. Arterial oxygen saturation was normal. The mean pressure in the right atrium and the systolic pressure in the right ventricle and pulmonary artery were somewhat elevated.

On the basis of all the data, it was decided that a major portion of the child's pulmonary veins emptied into the left superior vena cava—coronary sinus complex.

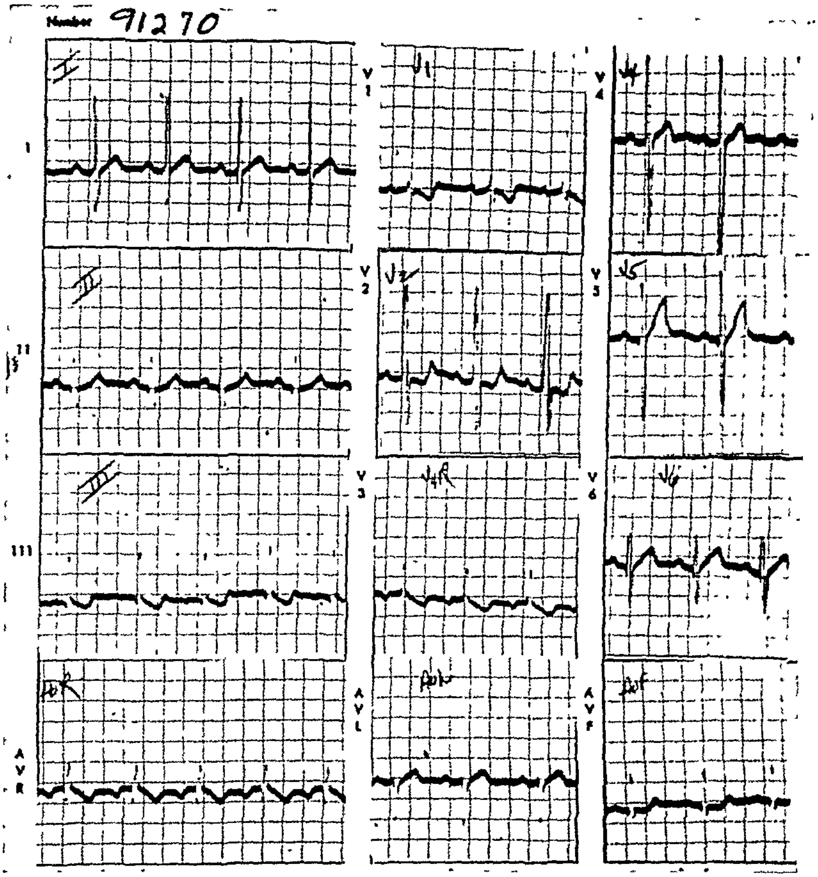

Fig. 1.

TABLE I. PREOPERATIVE (A) AND POSTOPERATIVE (B) CATHETERIZATION DATA

	A			B		
	O_2 CONTENT (VOL. %)	O_2 SAT. (%)	PRESSURE (MM. HG)	O_2 CONTENT (VOL. %)	O_2 SAT. (%)	PRESSURE (MM. HG)
AV				13.9		
RSVC	10.8			11.1		
LSVC (distal)	10.1			—		
LSVC (mid)	11.5			11.8		
IVC	11.3			13.6		
CS	16.8		(7)	5.1		(10)
RA h	15.2			12.1		
RA m	15.7		(7)	14.3 & 14.2		(0)
RA l	15.0			10.8 & 13.3		
RV l	15.8			14.4		
RV m	15.3		33/0	14.0		18/0
MPA	15.1		32/16	14.3		15/6
RPA	15.2			14.3		
SA	16.7	93.6	100/62	15.9	89.8	100/68

AV—axillary vein. RSVC—right superior vena cava. LSVC—left superior vena cava. IVC—inferior vena cava. CS—coronary sinus. RA *h, m, l*—right atrium, high, mid, low. RV l, m—right ventricle low, mid. MPA—main pulmonary artery. RPA—right pulmonary artery. SA—systematic artery.

On Aug. 20, 1956, she was operated upon (H. T. N.) through an anterior incision in the fourth left interspace. The left superior vena cava was found to be continuous with the coronary sinus, the proximal portion of the complex being hugely dilated. There was a localized continuous thrill over this area. The left pulmonary veins were dissected free and were found not to communicate with the left superior vena cava. A purse-string suture was placed in the wall of the coronary sinus and the structure explored with a finger. At the site of the thrill, a jet was felt which was found to issue from a single orifice, superiorly and posteriorly. Further exploration through this orifice indicated the presence of a chamber into which all pulmonary veins emptied. During this portion of the procedure, whenever the orifice was completely occluded, the patient would become very cyanotic. The finger could pass easily from coronary sinus to right atrium.

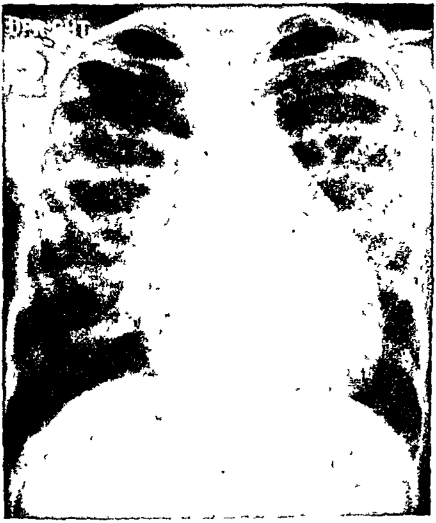

Fig. 2

A purse-string suture was now placed in the wall of the left atrium near the appendage. The exploring finger encountered a normal mitral valve. No pulmonary veins emptied into the chamber. In the postero-superior portion of the interatrial septum, a defect, admitting the finger tip, was found. Each time this defect was blocked the peripheral pulse could not be palpated.

It was obvious that all pulmonary veins converged to form a "chamber" which communicated with the left superior vena cava—coronary sinus complex. Systemic circulation was possible only because there was an interatrial communication through which mixed blood from the right atrium could pass to the left atrium, left ventricle, and aorta (Fig. 3, *A*). Correction of the anomaly would involve the creation of a passage between the confluence of pulmonary veins and the left atrium and obliteration of that between pulmonary veins and coronary sinus.

The Nichols guillotine knife was inserted along the finger into the left atrium and the septum between it and the common pulmonary vein "chamber" [illegible] as possible. Finger manipulation further enlarged this new passage and there was now relatively unobstructed flow of pulmonary vein blood into the left atrium. The communication between the common pulmonary vein and coronary sinus was then obliterated by multiple sutures (*Fig. 3, B*).

The postoperative course was uneventful and the child was discharged on the tenth day. Throughout the period, a moderately loud systolic blow was heard in the second and third left interspaces. The diastolic murmur was no longer present and the second sound at the base to the left of the sternum was normal.

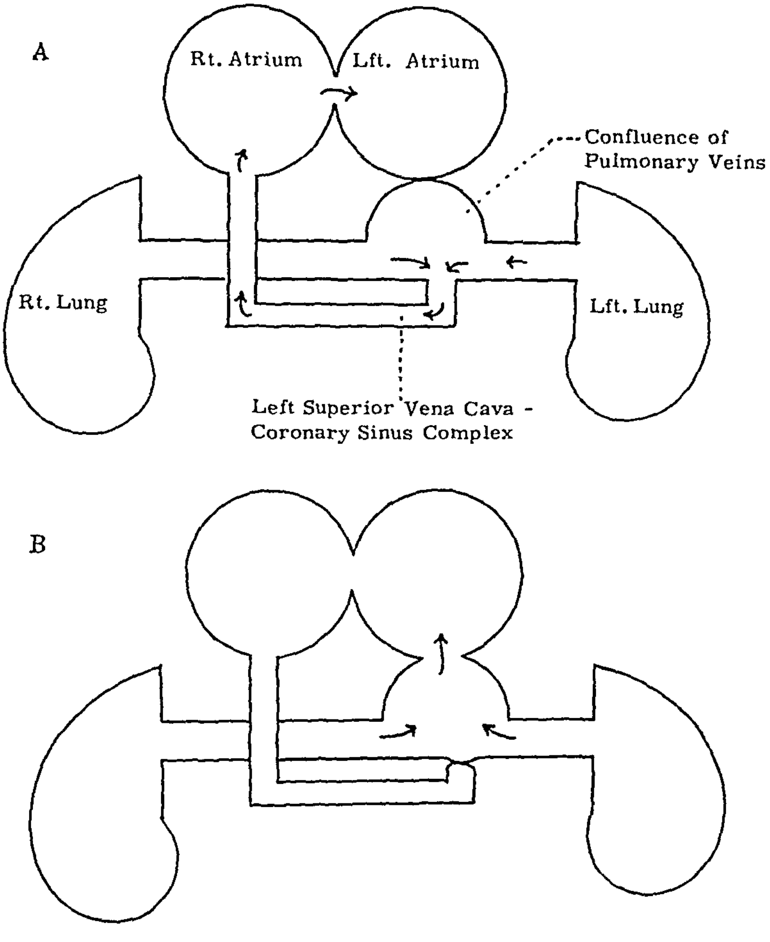
A
Rt. Atrium
Lft. Atrium
Confluence of Pulmonary Veins
Rt. Lung
Lft. Lung
Left Superior Vena Cava - Coronary Sinus Complex
B

Fig. 3.—*A*, Course of the circulation before surgery. *B*, Course of the circulation postoperatively.

Second Admission.—Fourteen weeks later she was re-admitted. Full activity had been allowed after a period of one week at home and her exercise tolerance was now reported to be normal. She no longer would become short of breath on brief exertion. To the parents she appeared completely asymptomatic. On physical examination the systolic murmur was still present. She had gained 5 pounds.

Laboratory data: There were 13.3 grams of hemoglobin. The hematocrit was 43 per cent. The electrocardiogram showed no change. The data secured by cardiac catheterization appear in Table I, B. Cardiac catheterization was performed through the left brachial vein. On several occasions the tip passed through the coronary sinus into the left superior vena cava. There was no evidence of a left-to-right shunt into the left superior vena cava or the coronary sinus. Averaging all five venous inflow samples, there was a step-up of 1.8 volumes per cent in the right atrium. Leaving out the coronary sinus sample, the step-up was only 0.3 volumes per cent. Ordinarily these figures would not be considered distinctive of a left-to-right shunt at the atrial level. However, the two samples from the mid-portion of the atrium contained a significantly greater amount of oxygen than did the other three, and the rise was continued through right ventricle and pulmonary artery. It was considered that there was a small left-to-right shunt at the atrial level. The pressure in the right atrium, right ventricle, and pulmonary artery was normal.

The result of operation is considered to be excellent. Unfortunately, there is evidence that the interatrial communication is still of functional significance. Whether this is an actual defect or a stretched patent foramen ovale is unknown. The eventual importance to the child also is unknown. However, it certainly does not pose the threat of the original condition.

DISCUSSION

The anomaly represents persistence of the common pulmonary vein trunk through failure of its absorption into the wall of the left atrium. Instead, it came to communicate with the left horn of the sinus venosus.

By some the patient would be described as having a triatrial heart. From our acquaintance with descriptions of "cor triatriatum" in the literature it seems obvious that most of these represent anomalous development of pulmonary veins rather than abnormal partitioning of the left atrium.

Once the anatomic situation is appreciated, the surgical therapy is relatively simple and can be performed rapidly. More effective than the incision and dilatation technique used in this patient would be an incision between the confluence of pulmonary veins and the left atrium followed by the use of a backward cutting punch and removal of tissue.

SUMMARY

In a 6-year-old child all pulmonary veins were found to drain into the coronary sinus at its junction with a persistent left superior vena cava. There was a small interatrial communication. A passage was created between the confluence of pulmonary veins and the left atrium; that between the confluence and the coronary sinus was then obliterated.

Postoperative catheterization demonstrated that the shunt into the coronary sinus was no longer present. There was now evidence of a small shunt from left atrium to right atrium. Pulmonary pressure, somewhat elevated before surgery, was now normal.

HUFNAGEL VALVE SURGERY FOR AORTIC INSUFFICIENCY

Technical Considerations and Report of Cases

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It is generally recognized that the prognosis of patients with severe aortic valve insufficiency is extremely grave. During recent years concerted effort has been directed toward discovery of a surgical solution for this problem. Of the various approaches that have been reported none has proved as successful as the one devised by Hufnagel—insertion of a plastic ball-valve into the descending thoracic aorta.

At best, the Hufnagel operation must be considered palliative since it fails to improve the hemodynamics of the coronary and brachiocephalic circulations. However, it does reduce by as much as 75 per cent the excessive work load to which the heart is subject in the presence of aortic regurgitation. In all probability, replacement of the damaged aortic valve with an acceptable prosthetic device will eventually be possible, thereby abolishing regurgitation completely. But considerable time must elapse before perfection and wide acceptance of such a procedure can be anticipated. In the interim, for those patients with clinical features warning of progressive deterioration and death, the potential benefits of a Hufnagel valve should not be denied. Patients in such a perilous state have a life expectancy of approximately 1 year, or even less, despite the most rigorous medical therapy. Although the surgical and late mortality of the Hufnagel operation has been high, the majority of the patients who survive the operation have been significantly benefited. Improvement in some has been dramatic.

Insertion of a Hufnagel valve into the descending thoracic aorta requires temporary cross-clamping of this vessel. Interruption of the distal aortic circulation for more than 15 minutes may result in irreversible spinal cord damage and other serious or fatal complications. In the animal laboratory and autopsy room, practice insertions can generally be accomplished easily and rapidly by simply excising a short segment of the aorta and pulling each end of the aorta over the appropriate end of the valve. In our early experiences with living patients, however, we soon encountered difficulties. The

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diseased aorta of these patients is likely to have lost its elasticity and to tear readily On more than one occasion we lost valuable time when the short retracted lip of a divided aorta tore between the grasp of forceps that were being used to pull it over the cuff of a valve For a while we tried to avoid the potential hazards of such a delay by placing a temporary bypass around the segment of aorta that was to be occluded during placement of the valve Eventually, however, with suggestions contributed by various members of the operating team, a technique evolved which permits aortic occlusion to be limited to less than 5 minutes Since we understand that others have been deterred from performing this operation because of difficulties similar to those which we have encountered, it seems worth while to report a technique which has permitted rapid placement of a valve, the aorta having been occluded, on occasion, for less than 3 minutes The use of a temporary bypass is no longer considered necessary

OPERATIVE TECHNIQUE

For the definitive part of this operation we consider that the operating team should include four surgeons and two scrub nurses To each member of this group are assigned specific responsibilities and, for the benefit of those who may be inexperienced, these are rehearsed immediately before the aorta is clamped and the valve inserted Constant vigilance on the part of the anesthesiologist and of the cardiologist who is monitoring the electrocardiographic equipment is obviously important

The patient is operated upon in the right lateral decubitus position A standard posterolateral thoracotomy incision is used and carried through the fifth intercostal space Short posterior segments of adjoining ribs are resected, according to the need for increased exposure It is sometimes helpful to use two rib spreaders, one at each end of the wound Following exploration, the aorta is mobilized from the origin of the left subclavian artery distally, for a variable distance, depending on the length and diameter of the plastic valve that is selected for use Dissection around the aorta may be tedious and time consuming, particularly when aortitis has produced a great deal of fibrous tissue reaction, as is not infrequently the case It may be necessary to divide four or five pairs of intercostal arteries, as well as the bronchial arteries that are encountered

We keep our Hufnagel valves and their multiple point fixation rings continuously sterile by storage in 1 700 Zephiran solution At least one of each of the four standard sizes should be available for every operation* At the operating table the valves are washed and placed in a solution containing 100 mg of heparin to 500 ml of normal saline It is important that the valves be handled only with the special valve holder* and that scratching or marring of the inner surfaces of the valve or the valve edges be avoided. A defect on a surface that is exposed to the blood stream may prove to be a site for thrombus formation.

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*Formerly we kept two valves of each size on hand so a replacement would always be available We found however that the number and urgency of these operations do not require this The valves are obtained from Brunswick Mfg Co 61 Hampshire St Boston 20 Mass the valve and ring holders from Geo P Pilling & Son Co 3451 Walnut St Philadelphia Pa

The largest usable valve should be selected; but one should avoid choosing one that is too large, since time may be lost during unsuccessful attempts to introduce it. One must take into consideration, too, the length of the valve and the amount of the aorta that will be resected, in order to prevent kinking of the vessel after the valve has been inserted. Since the maximum diameter of the valve is greater than that of the aorta, the reconstituted vessel will be displaced to the left. If too much of the aorta is resected there will be greater difficulty in placing the valve and excessive kinking where the proximal end of the aorta joins the valve. The same will be true if the valve is placed too close to the aortic arch. We have never found it necessary to resect more than 2 cm. of the aorta, no matter how long the valve. Sometimes there can be considerable discrepancy in the size of the aorta at its two divided ends, particularly in persons who have had syphilitic aortitis with proximal dilatation of the vessel. Under such circumstances it may be desirable to place the valve in a more distal position, where the aorta is more uniform in size. In any case, the smaller end of the aorta must be used as a guide to selecting the size of the valve that will be inserted.

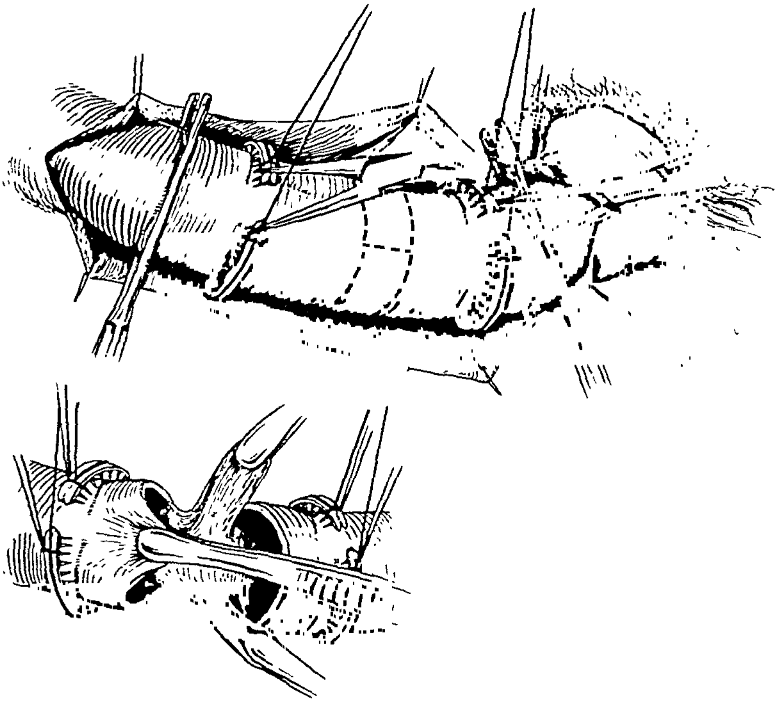

Fig. 1.—Preparation of descending thoracic aorta for placement of Hufnagel valve.

The two nylon multiple-point fixation rings of the selected valve are prepared in advance by anchoring a strand of heavy silk (No. 3) into the circumferential groove of each with four or five fine silk ligatures. These rings are then placed around the proximal and distal ends of the mobilized segment of aorta. A special ring-holding clamp with a ratchet is attached to each of these rings and the clamps are held open by the assistants who have been selected to close the rings over the cuffs of the valve after it has been inserted. Large Potts clamps (straight, angled, curved, or spoon-shaped, according to ease of placement) are also held open, proximal and distal to the rings, ready for occlusion of the aorta and isolation of its mobilized segment (Fig. 1). *Another assistant holds one of two aspirators, ready to remove any blood that appears in the operative field.* The surgeon holds long, straight scissors (Nelson) in one hand and Russian forceps in the other. The instruments that may be needed are so placed as to be immediately available, all others being set aside. The surgeon then reviews the responsibilities of each team member and asks the anesthesiologist and cardiologist for an evaluation of the patient's condition.

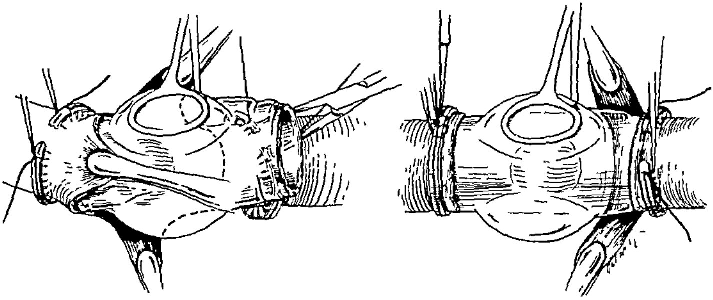

Fig. 2.—Insertion of Hufnagel valve. The lateral lip of the aorta is better elevated over the valve cuff with 2 or 3 pairs of forceps. After the aorta has been completely divided, a Semb forceps (sharp curve) serves well to grasp the free medial segment for traction while inserting the proximal end of the valve.

At a signal from the surgeon, who has assured himself that everything is in good order, the aorta is occluded first at the proximal end and then at the distal end of the isolated segment. The following steps are next carried out, deliberately, avoiding haste:

1. The aorta is *partially* transected (about two-thirds) with Nelson scissors at the two points, 1 or 2 cm. apart, at which the ends of the valve will be introduced.
2. A longitudinal cut is then made between the two partial transverse cuts, dividing the intervening segment of the aorta into two equal "side straps" (Fig. 1).
3. The surgeon is handed the selected valve in the valve holder, and he checks to make sure that the valve is properly positioned.
4. The surgeon slides the distal end of the valve along the medial (uncut) wall of the aorta into its open distal end, as he and an assistant lift the cut, lateral portion of the aortic wall over the cuff of the valve and past its groove with two pairs of Russian forcep

5. When this end of the valve is snugly in place, with sufficient aortic lip over the edge of the valve, the selected assistant brings up the plastic ring and secures the aortic lip in the groove of the valve cuff by closing the ring-holding clamp. The ratchet of the clamp locks the ring in place.
6. The surgeon divides the remainder of the aorta at the site of the distal transverse cut. Potts 60-degree scissors are useful for this purpose. The proximal stump of the aorta retracts cephalad. Still attached to it is the segment of the aorta which will be resected and this segment will serve as a very useful "handle" and "guide" for the next step.
7. The end of this segment is grasped in a Semb forceps (sharp curve), or its "side straps" are grasped with two pairs of Russian forceps, and traction is applied to it. Using its medial surface as a guide, the surgeon slides the proximal end of the valve into the corresponding aortic stump, the lateral free edge of the aorta again being lifted onto the valve cuff with forceps.
8. The proximal end of the aorta is fixed to the valve cuff with the multiple-point fixation ring, as was done at the distal end.
9. The surgeon punctures the aorta close to the valve with a 20-gauge needle on a Luer-Lock syringe which has been partially filled with dilute heparin solution. He attempts to fill the valve chamber with the solution, aspirating as much of the contained air as possible.
10. The syringe is removed and the open needle is held in place with a clamp so that residual air may escape through it as the *distal* Potts aortic clamp is opened and blood enters the valve from below.
11. The proximal Potts aortic clamp is opened *gradually*. The valve immediately begins to function. It is felt that this proximal clamp should be opened over a period of perhaps 3 to 5 minutes, depending on changes in cardiac rhythm and rate, and on the response of the blood pressure. Since aortic circulation has been re-established, time is no longer a primary factor.
12. As soon as possible, the heavy silk ligatures in the grooves around the valve rings are tied, even before the proximal aortic clamp is completely opened or removed. This permits removal of the ring holders. Stainless steel wires (No. 26) are then threaded through the holes in the rings and tied, to hold the rings securely and permanently in place.

During the period that the aorta is clamped, even though brief, the blood pressure proximal to the clamp may rise to extreme heights. On occasion we have used a short-acting hypotensive drug (Arfonad) to counteract this. Should marked tachycardia or drop in blood pressure occur after the aortic clamps have been removed it may be advisable to recompress the aorta, at least partially, until stabilization results.

We have not encountered major bleeding from the aortico-valvular junctions. Some bleeding has occurred from between the fixation points, particularly at the proximal end of the aorta when it is significantly larger than the distal end. Such bleeding is readily controlled by tightening the cuff with 4-0 arterial silk sutures or by the next step, which is carried out in any case. This involves placing strips of Ivalon sponge or plastic fabric about the aorta, above and below the valve rings, so as to tighten the aortic walls snugly to the free ends of the valve which protrude beyond the rings into the lumen of the aorta. As Hufnagel has indicated, these tightly sewn strips obliterate the groove between the aortic wall and valve edge, decreasing the likelihood of thrombus formation at these sites. If these strips cover the valve rings as well as the valve ends, they are less likely to slip out of position.

In the past we have also sewn a sheet of Ivalon sponge around the main portion of the valve, believing that this served to muffle the noise of the valve to a considerable extent. The Ivalon sheet will no longer be necessary for this purpose, since "silent" valves are now available. But it may still have some value in that it serves as padding between the valve and the spine and it also helps in anchoring and stabilizing the valve, since the pleural edges can be sutured to it. A single sheet of sponge can be used for both purposes—to cover the valve and to cinch up the aorta around its ends. The remainder of the operation does not differ from other major thoracotomies. We have used closed pleural drainage routinely.

The postoperative management is similar to that of other major thoracic operations. Drainage tubes can generally be removed within 1 to 3 days. We have felt that routine use of prophylactic antibiotics is desirable, because of the foreign bodies that have been introduced. We have not used anticoagulants, but it may prove advisable to do so. There seems to be a tendency for the red blood count to drop off during the early postoperative course, possibly due to valve trauma. Hematologic studies should therefore be carried out at frequent intervals until the red count and hematocrit have become stabilized. It has been our arbitrary practice to defer ambulation and hospital discharge for these patients longer than for most. Gradual ambulation has generally been started on about the third postoperative day and most of the patients have been discharged near the end of the second week.

SURGICAL RESULTS AND EXPERIENCES

Our experience with Hufnagel valve surgery includes 21 cases between the ages of 10 and 63. Of these, 3 were in the second decade of life, 3 in the third, 4 in the fourth, 7 in the fifth, and 2 each in the sixth and seventh decades. All had severe aortic regurgitation, and all but 1 had developed signs and symptoms of ominous import. The child of 10, originally explored for a patent ductus arteriosus, was found to have a sinus of Valsalva aneurysm which was obliterated with mattress sutures over pieces of Ivalon sponge. Retrograde aortography during the operation and angiocardiography after it failed to reveal a rupture of the aneurysm with a left-to-[illegible] [illegible]ause of severe aortic regurgitation, attributed to a dilated valve ring (Marfan's syndrome), a Hufnagel valve was inserted 2 months later. The child's response to this surgery has been considered good. In 5 of the remaining patients, aortic insufficiency was attributed to syphilitic aortitis. Rheumatic aortic valvular disease was considered the basic etiology in the remaining patients.

Three patients died on the operating table with terminal ventricular fibrillation and asystole. In one of these the ventricular fibrillation appeared *during* a 4 to 5 minute occlusion of the aorta. In the second, it occurred after the valve was functioning, following a 10-minute occlusion of the aorta. The third patient, 61 years old, had had a left pneumonectomy for chronic suppurative disease, with multiple lung abscesses, 2 years previously. At autopsy, he was found to have severe aortic insufficiency, moderate aortic stenosis, mild mitral stenosis and insufficiency, severe generalized arteriosclerosis, and moderate coronary sclerosis. Total aortic occlusion had lasted 15 minutes. Cardiac arrhythmia first developed several minutes after good valve function had been established. In an early case, death occurred on the third postoperative day with acute renal shutdown and paralysis of the lower extremities. Her aorta had been occluded for a prolonged period due to technical difficulties. A recent 63-year-old patient died a week following surgery with acute fulminating septicemia.

In addition to the 5 hospital deaths there have been 4 late deaths. In one of these, death was not directly related to the valve disease or to the Hufnagel operation, which had been performed a year and a half previously. Death was due to peritonitis which followed gastrectomy for ulcer and a secondary laparotomy for acute bowel obstruction. This patient did, however, have thrombosis of the right external iliac artery which had begun to manifest itself before the gastrectomy was performed and is presumed to have been embolic in origin. Another patient died a year postoperatively with acute bacterial aortitis. This patient, although improved early, had increasing anginal pain. His family physician referred him to a neurosurgeon who performed a thoracic sympathectomy which was complicated by an empyema. The aortitis developed soon thereafter. A patient who had had a bowel resection for mesenteric thrombosis 1 month following his Hufnagel operation died suddenly 3 months following it, while visiting with a friend. His "valve noise suddenly stopped." He had had previous episodes of arrhythmia and it is believed that terminal ventricular fibrillation occurred. The fourth patient died in a shock-like state, with cold, pulseless lower extremities, 5 months following surgery. Permission for autopsy was refused.

Of the 16 patients who survived the operation and left the hospital, all were considered to be at least temporarily improved. All those who still survive, except for the most recent one, have returned to their previous occupations. Since the prognosis of almost all these patients was considered to be extremely grave, we consider the over-all salvage to have been gratifying, despite the high early and late mortality An 18 year old boy was the only patient whose prognosis without surgery was thought to be relatively good and he has done exceptionally well All of the others had been in failure or they had severe angina, episodes of syncope or both The first of these patients, a 50 year old Negro man, was operated on in April, 1954 His response was excellent and has been maintained, although he has been rehospitalized several times for acute alcoholism

The high incidence of thromboembolic complications, early and late, presents a serious problem These probably occurred in 5 of the 21 patients The incidence has been lower since our present technique became established in January, 1956 (1 in 9) but these patients have not been followed for as long a period of time Our experience does indicate that early operative mortality is related to the length of aortic occlusion There were no operating room deaths among the 9 patients operated upon by our present technique and the only hospital death was due to septicemia Aortic occlusion was limited to 5 minutes or less in all of these patients except 1 In this case, one of the multiple point fixation rings of the selected valve proved to be defective Despite having been tightly fixed in position, it twice slipped off the valve cuff, with loss of considerable blood A different ring was employed for the third fixation and this held securely The patient, who has made a good recovery, had three periods of aortic occlusion, totaling perhaps 12 to 15 minutes There were, however, periods of aortic blood flow between occlusions Since this experience when a nylon ring seems to fit too loosely we now take the precaution of shaving off, with a scalpel a little of the plastic from the notches at its ends

It is not unusual for a surgeon to be discouraged by his early experiences with a new technique and to find that results improve as its potentialities are further explored and more and more of the pitfalls are avoided or overcome Accepting the fact that this operation is not ideal, in that it does not correct the physiologic problem completely, we are convinced that it does have proved value and that it should continue to be recommended for patients who are not likely to survive until a more completely restorative procedure becomes available We recognize that the mortality has been very high We believe that it will be less high in the future The operative risk will doubtless remain great for the patients most urgently in need of help—those with very large hearts, in chronic failure, etc—no matter what surgical procedure may become available For such patients, however, a considerable risk seems acceptable if an operation offers better than a 50 per cent chance of prolonging their lives and relieving their symptoms

SUMMARY

We have performed the Hufnagel operation for aortic insufficiency on 21 patients Three of these patients died on the operating table with terminal ventricular fibrillation In addition there were 2 hospital deaths and 4 late deaths In 6 or 7 of these patients (about 33 per cent) death can be attributed

directly to the operation and its complications. Experience indicates that refinements in technique will go far toward reducing this high mortality. The technique which we presently use is described.

The 12 patients who survived have all been significantly improved and, except for the most recent one, have returned to their previous occupations. We believe that until an operation is devised which can abolish the regurgitation completely, with as great or greater safety, the Hufnagel operation should be recommended for patients with severe aortic regurgitation who have developed ominous signs.

ADDENDUM

Two additional patients are doing well over 3 months following their operations. On the other hand, a young man of 20 years of age, who was the most recent of the cases reported above, after marked initial improvement, developed a fulminating septicemia and at autopsy was found to have a large thrombus in the valve.

One of the authors (W. S. C.) has proposed that insufficiency could be eliminated for all but the coronary circulation if end-to-side shunts were introduced from below the Hufnagel valve to the innominate and left common carotid arteries, after which these vessels and the left subclavian artery would be divided. Preliminary work with animals for development of such a technique has not been carried out and it does seem that successful excision and replacement of the aortic valve proper, under cardiac bypass, will be developed and should provide a better solution to the problem.

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SOME CLINICAL AND PATHOLOGIC ASPECTS OF COARCTATION OF THE AORTA AND AORTIC ARCH SYNDROME

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Many problems concerning the coarctation of the aorta remain unsolved. The area of coarctation and the pathology of the coarctation proper have been the subject of extensive studies. However, very little attention has been paid to changes in other parts and in the branches of the aorta. The problems concerning the collaterals which are so important from the point of view of surgery, are far from being solved.

It is assumed that aortic coarctation is caused by a developmental disorder which occurs during the early weeks of intrauterine life by the failure of union between the parts of aorta growing from the heart anlage and those from the blood islets. This explains the various forms of coarctation, the various localizations, as well as the frequently observed changes in other blood vessels, such as the branches of the aortic arch and the intercostal arteries.[1] We believe that the developmental disorder will not always be restricted to the area of coarctation proper. Variable changes will occur in the ascending aorta, the immediate prestenotic segment as well as the post-stenotic area. In such cases the ascending aorta is either normal or hypertrophic, while the segment immediately proximal to the site of coarctation is often hypoplastic in its entire length, in spite of the fact that systolic pressure is much higher than in the post-stenotic area. In addition, the postcoarctation area itself is also abnormal; early in its development it shows hypoplasia, while later on secondary degeneration develops as a result of diminished pulse amplitude, affecting mainly the media.[2] The weakened vascular wall is then locally dilated by the vortex effect leading sometimes to aneurysm formation and rupture.[3]

The development of the postcoarctation dilatation may be traced back to the following causes:

The changes occurring in the uppermost dilated intercostal arteries, which serve as collaterals, cannot be considered to be due to a simple compensatory effort or to an hypertrophy. It has been found that within 3 to 4 cm. from the aorta, these arteries are thin walled, excessively dilated and do not pulsate. For this reason the ribs in this area show no erosion. In these segments the media is richer in elastic fibers and elastic elements are relatively more abundant than muscular elements when compared with the media of normal muscular type intercostal arteries (Fig. 1). Peripheral to this segment the intercostal arteries are thinned and a true "stricture" is visible in an area

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a few centimeters in length, distal to which another relatively dilated segment occurs; in the latter area the vascular wall is thicker, the vessel pulsates intensively and is tortuous, forming multiple loops. This latter vascular segment anastomoses with the collaterals coming from the back muscles; the costal erosion is caused by the loops and their pulsation. The segment peripheral to this is narrowed again until it reaches the internal mammary artery.

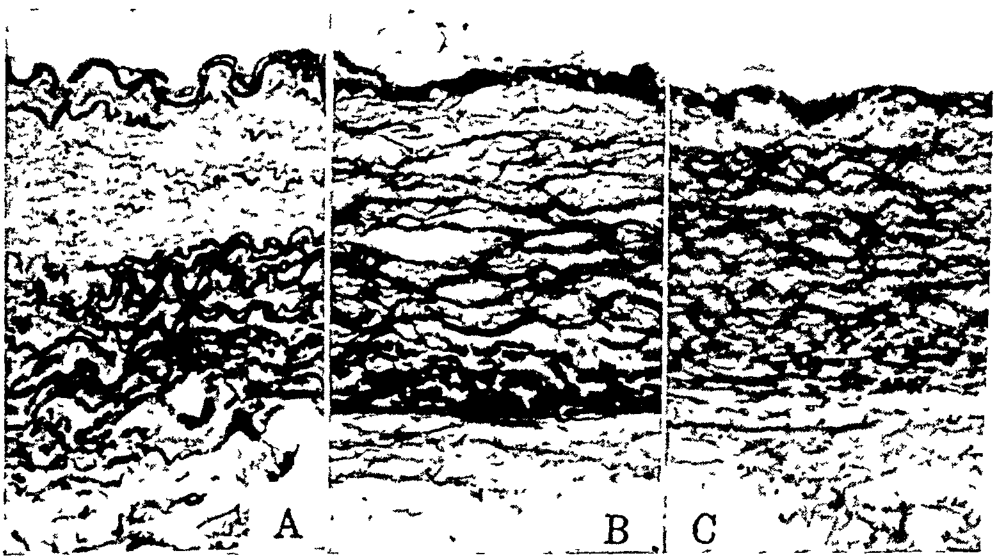

Fig. 1.—*A*, Normal intercostal artery (control)
B, Dilated collateral intercostal artery with a diameter of 6 mm.
C, Dilated collateral intercostal artery with a diameter of 8 mm.

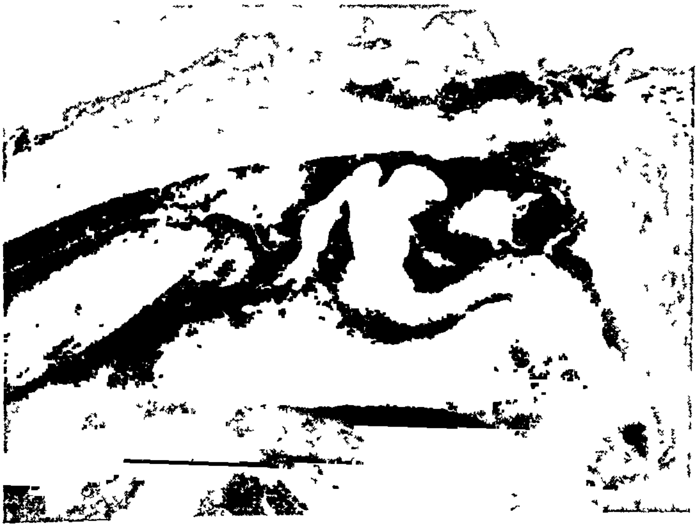

Fig. 2.—The para-aortic segment of a dilated intercostal artery below the site of coarctation. Post-mortem specimen.

Thus, in the single intercostal collateral there are two narrowed and two dilated segments (Figs. 2 and 3). It is believed that here, too, the strictures arose at the sites of union of segments grown from a single anlage. The two dilated segments differ in behavior; the one next to the aorta does not pulsate, while the peripheral, convoluted one shows marked pulsation. We have been unable to find in the literature any explanation of this phenomenon. It is equally unknown why a certain area of these vessels is of such a tortuous course. As one tries to interpret these observations one is not even certain whether in every intercostal collateral artery, or throughout its course, the direction of blood flow is toward the aorta. These problems have been subjected to further study.

Not infrequently the left subclavian artery or the other major branches of the aorta show signs of hypoplasia, similar to those seen in the intercostal arteries. The left subclavian artery is frequently stenosed or totally obliterated. However, this is restricted to only one segment of the vessel. The obliteration is often not at the site where the artery branches off from the aorta but a few millimeters distal to it. The artery resumes its normal diameter in most cases at the site of its division, resulting in a dumbbell pattern (Fig. 4).

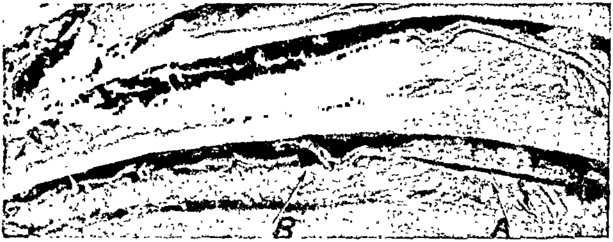

Fig. 3.—The peripheral narrow (*A*) and the convoluted distal (*B*) segments of the intercostal artery shown in Fig. 2

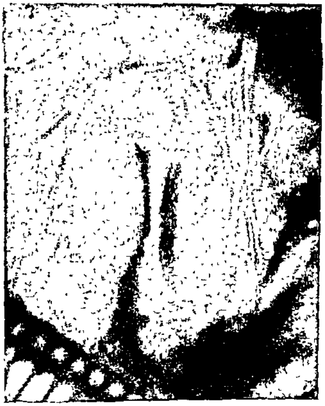

Fig. 4.—D. A., male, aged 25 years. Hypoplasia of the left subclavian artery. Photographed during operation.

This type of stenosis affecting the big arteries branching off from the aorta, as it occurs in association with coarctation of the aorta, presents a pattern closely similar to that seen in cases of aortic arch syndrome Although it is unquestionable that the latter may also be due t [illegible] arteritis, the close resemblance makes it quite likely that in some of the cases of aortic arch syndrome a developmental disorder similar to that occurring in coarctation might be involved. Here, too, the stricture may develop at the site where the vascular buds growing from the different blood islets unite and this would explain also the segmental, circumscribed nature of the abnormality. The pathologic change might develop in two stages. The primary change would be a developmental disorder arising during intrauterine life. The secondary lesion would be an inflammation affecting the histologically inferior hypoplastic vascular wall ("locus minoris resistentiae") later in life.

In one of our cases of aortic syndrome, histologic study has revealed that in the area of segmental obliteration, especially in the intima, the smooth muscle elements increased in number and showed unusual distribution, the isolated smooth muscle cells were surrounded by rings of fibroelastic tissue (Figs. 5, 6, and 7). These changes suggest the presence of a disorder of tissue development in the intima (hamartosis) that made the vascular wall susceptible to infection and thrombus formation.

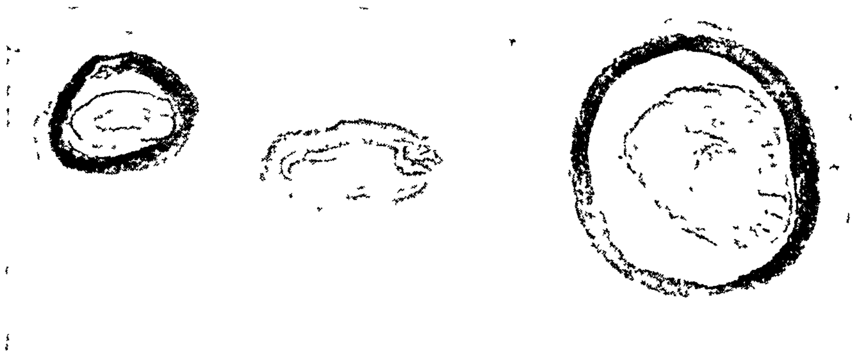

Fig. 5.—Cross section of the innominate artery (big diameter), the subclavian and the common carotid arteries. In all three vessels, the media had been detached circularly from the intima, as a result of operation. The lumen was filled with organized thrombus, showing small-caliber recanalization.

The correlation of these pathologic observations with clinical and surgical findings leads to the following practical conclusions.

Considering the different segments of the coarctated aorta, the surgical significance of the changes affecting them will be seen as follows. The ascending aorta is of no significance as far as surgery is concerned. On the other hand, both the pre- and the postcoarctation segments are of decisive significance. In one of our patients (I. B., male, aged 17 years) it was found at operation that the precoarctation part of the aorta (about 2 cm. long) showed hypoplasia and a diameter much smaller than normal. The subclavian artery had the diameter of an index finger and its wall, like that of the aortic arch, was sclerotic. After resecting the coarctated part of the aorta, an end-to-end anastomosis was done. Both above and below the coarctation the aorta was clamped by using a Crafoord clamp at each site. Owing to lack of space, the proximal clamp had to be placed higher on two occasions. When the anastomosis was completed it was found that at the site where the Crafoord clamp was first applied it had completely severed the intima and media of the aorta, which had been pulled apart by tension; this defect was bridged only by the adventitia. For this reason the anastomosis had to be resected and a new anastomosis performed. This, too, was damaged. The two failures forced us to free the subclavian artery, to cut it high, proximal to where it divided and, by pulling the end down, to create an anastomosis between the subclavian and the distal part of the aorta. The thick postcoarctation aortic wall was not damaged by the Crafoord clamp. The patient made an uneventful recovery and was discharged 3 weeks later.

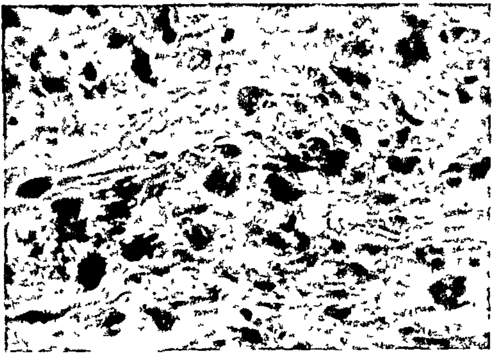

Fig. 6.—High power view of the junction between intima and thrombus. In the fibrotic matter disarranged isolated smooth muscle cells can be seen. These do not form bundles but lie in different directions separated by fibroelastic tissue.

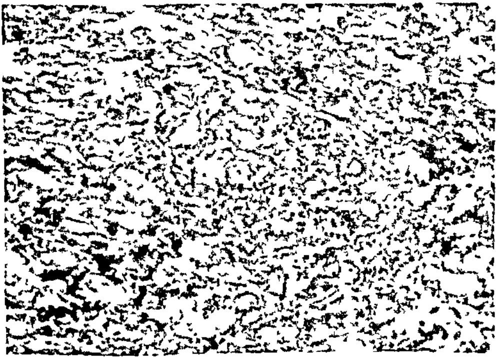

Fig. 7.—High power view of the fine fibroelastic network separating the disarranged smooth muscle cells the nuclei of which can be seen faintly in the meshes of the elastic fibers (Weigert's elastic stain).

An anastomosis made with the hypoplastic aortic precoarctation segment may lead to even more serious complications. The precoarctation aortic segment of N. S. (male, aged 20 years) showed hypoplasia while the postcoarctation segment was enormously dilated. After resecting the coarctated part, the two aortic ends were united by an end-to-end anastomosis. No bleeding was seen after the release of the clamps and no complications were noted during the operation. Three weeks later the patient was discharged free of complaints and was admitted to a department of internal medicine, where he spent an additional 5 weeks without having any significant complaints He then developed left thoracic pain. A few hours later he suddenly spit a mouthful of blood and collapsed. After developing severe dyspnea, the patient died in a short time. At necropsy a small apple-sized, partly fresh and partly old hematoma was found at the junction of the arch and the descending aorta, surrounded by a connective tissue capsule, 2 to 3 mm. thick. At one point the connective tissue wall had broken through into the left superior lobe of the lung. At the dissection of the aorta it was seen that on the precoarctation side of the suture line there was a smooth opening, through which one could enter the sac of the hematoma. Higher up, in the precoarctation segment, where it was damaged by the Crafoord clamp, there was a semilunar area covered on the outside by the adventitia and on the inside by newly grown endothelium. This, however, was not the cause of the hematoma (Fig 8). A similar cause was responsible for the fatal outcome of another of our cases, 59 days after operation. The conclusion that can be drawn from these 3 cases is that an end-to-end anastomosis using a hypoplastic precoarctation segment, especially under tension, may lead to very grave consequences. In the 2 latter cases, the sutures placed in the hypoplastic precoarctation aorta wall held well for some time, but a few weeks later single sutures cut the wall as a result of increased pulsation and tension. This took place in the precoarctation segment only, while in the postcoarctation segment no damage was caused either by the sutures, or by the Crafoord instrument. For this reason we have recently decided to use a Blalock clamp on the precoarctation segment, placing

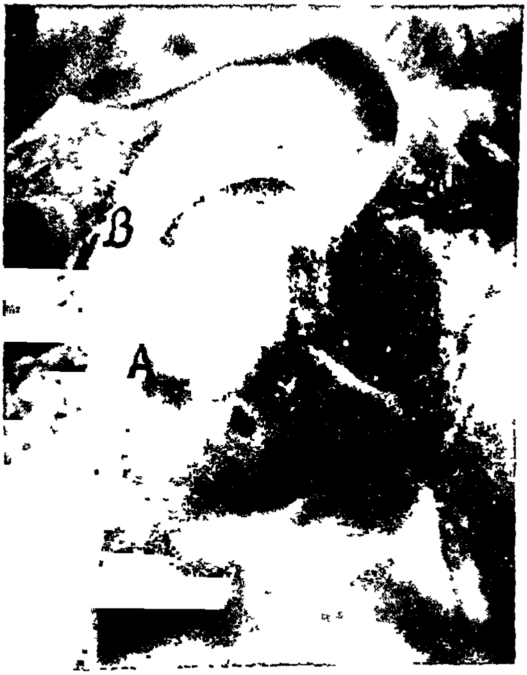

Fig 8 —N. S , male, aged 20 years Post-mortem specimen The insufficient part of the suture *line (A) and superior to it the impression made by the Crafoord clamp (B)* are visible

it anterior to the subclavian artery; thus, it cannot slip and need not be closed tightly. The practical importance of late suture insufficiency is best illustrated by the fact that we have lost a total of 4 out of 20 patients operated upon, 2 of the 4 because of this complication.

The collaterals which open into the postcoarctation segment tear easily and can be ligated only with difficulty. When they are ligated too close to the aorta, the silk thread may cut them off the thick, hard aortic wall. When ligated more distally the increased pulsation after the anastomosis has been made may rupture the stumps, resulting in a serious hemorrhage. Hence they should be ligated very carefully, near to the aorta if possible, but taking precautions to prevent their being torn off. In view of these difficulties Crafoord[4] has recently decided not to free these vessels and not to resect them. Thus the postcoarctation segment is not mobilized and the complications due to damage to the collaterals are avoided.

In D. A., a 25 year old male, the subclavian artery showing hypoplasia had been resected to ensure an increased mobilization of the aortic arch and precoarctation segment. The latter, too, showed hypoplasia and on the aortic arch, a circular detachment was visible proximal to the left common carotid artery. After the coarctated area had been resected, the two ends were united by end-to-end anastomosis. As a result of the resection of the subclavian artery *and mobilization of the aortic arch, the sutures were not under tension.* The patient tolerated the operation well and was discharged 2 weeks later, recovered. The interesting feature in this case is the simultaneous occurrence of aortic maldevelopment and subclavian hypoplasia. Although the latter had proved to be passable on retrograde catheterization it could not have played a significant part in function, as the patient had no collateral circulation on the left side, which accounts for the absence of rib erosion there. Thus, the hypoplasia of the subclavian artery has the clinical significance that its resection represents no substantial loss and therefore it is worth while to sacrifice it in order to ensure a better mobilization of the precoarctation aortic segment.

SUMMARY

In the studies made thus far we were concerned mainly with those changes which occur in cases of coarctation outside the coarctated area: in the pre- and postcoarctation segments of the aorta, in the branches of the aortic arch and in the collaterals. Analyzing these one by one in the light of pathologic evidence, we have endeavored to show that all these rather neglected and ignored anatomic changes may play roles of considerable importance in the surgery for coarctation of the aorta, may profoundly influence our choice of the best surgical method, and may be of decisive importance in the outcome, favorable or unfavorable, of operation.

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DEHISCENCE OF THE DIAPHRAGM ASSOCIATED WITH FRACTURES OF THE PELVIS OR LUMBAR SPINE DUE TO NONPENETRATING WOUNDS OF THE CHEST AND ABDOMEN

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In this day of ever-increasing horsepower in the automobile engine, we may expect to encounter an increasing number of patients subjected to particularly violent trauma. We have recently seen 2 patients with extensive fractures of the pelvis and lumbar spine in whom dehiscence of the diaphragm also occurred. This prompted a review of our experience, and of similar cases reported in the American and British literature from 1946 through 1957, inclusive. Our interest is limited to those cases in which sudden and markedly increased intra-abdominal pressure caused the diaphragm to rupture. Cases in which there was an associated penetrating wound or in which the diaphragmatic injury was thought to be due to a fractured rib fragment were excluded.

RESULTS

In the review of patients treated at the Vanderbilt University and Thayer Veterans Administration Hospitals from 1946 through 1957, 9 patients with dehiscence of the diaphragm caused by nonpenetrating trauma were encountered. In 6 of these 9 patients, a fracture of the bony pelvis and/or the lumbar spine was also found. Seven of the 9 patients were males and all 9 patients recovered. Summary of the findings in those with fractures of the pelvis and/or lumbar spine, together with the pertinent x-ray studies, are presented in Figs. 1 through 6.

Although the interval between the accident and the patient's admission to the hospital ranged from 2 hours to 4 days, exploration was carried out in all patients within 5 hours after admission to the hospital. In 3 instances, a thoraco-abdominal approach was used; in 5 cases concomitant but separate incisions were made into the chest and the abdomen; and in 1 case the hernia was repaired through a thoracic incision. In 3 of the 9 cases, intra-abdominal injuries were found which required surgical care. In 1 case a lacerated spleen was removed. In the second case, a laceration of the left lobe of the liver required suture; and, in a third instance, a complete transection of the distal

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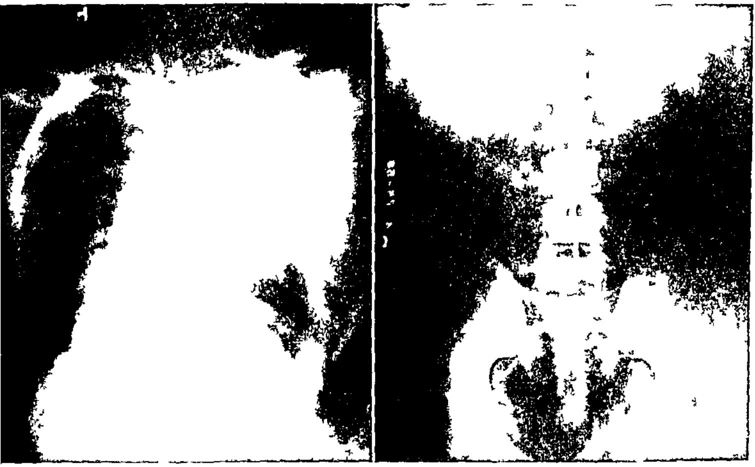

Fig 1 —Age—27 Year—1953 Etiology—auto crash Interval Prior to Hospitalization—3 days post trauma Extent of Diaphragmatic Tear—10 cm Associated Injuries—laceration of stomach

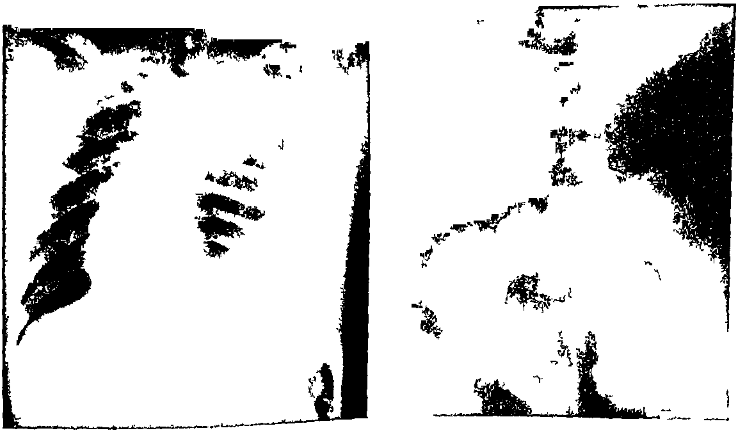

Fig 2 —Age—22 Year—1953 Etiology—mine accident Interval Prior to Hospitalization—36 hours post trauma Extent of Diaphragmatic Tear—14 cm Associated Injuries—none

ileum was found. This experience emphasizes the necessity for adequate exposure of both the chest and the abdomen in order that a complete exploration may be carried out. In all 9 cases, recovery from the procedure was complete and the patients were discharged from the hospital. The convalescence of 1 patient was prolonged because of a concomitant severe head injury which required nearly 6 months of hospitalization.

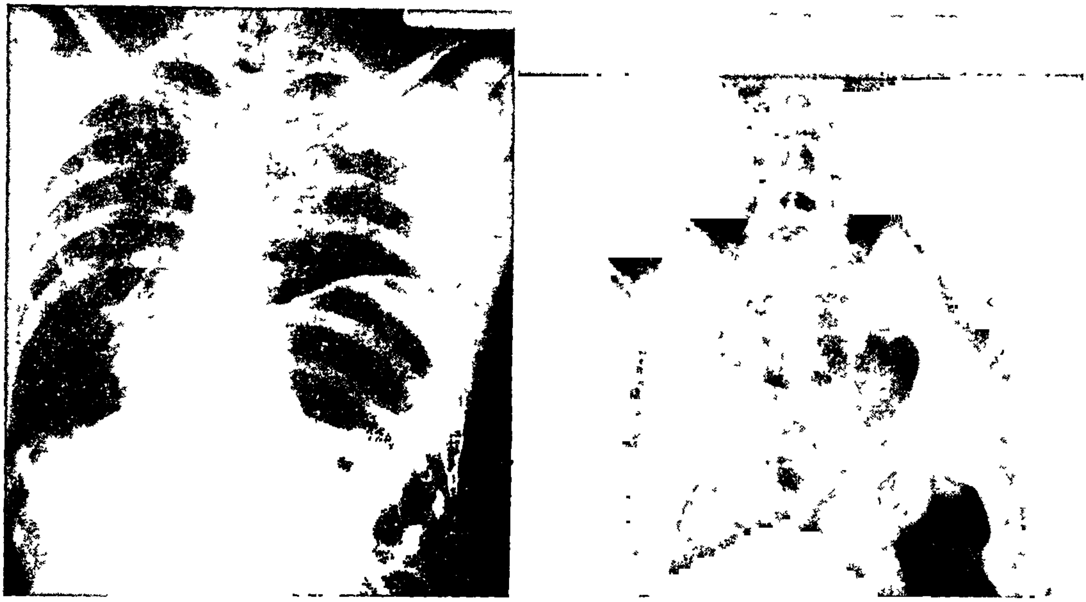

Fig 3.—Age—20 Year—1955. Etiology—run over by car Interval Prior to Hospitalization—2 hours post-trauma. Extent of Diaphragmatic Tear—16 cm. stellate. Associated Injuries—transection of ileum

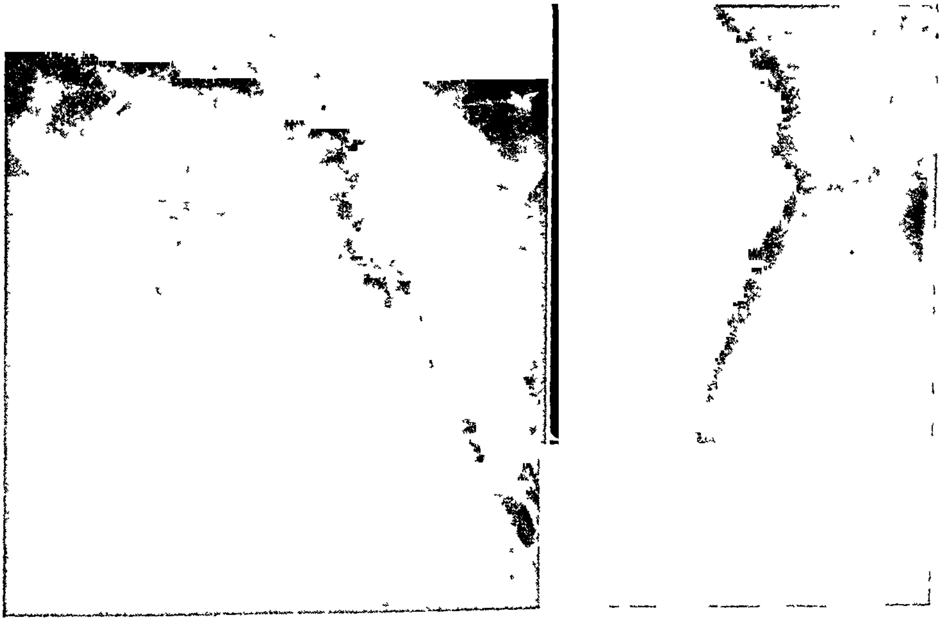

Fig 4—Age—29 Year—1957. Etiology—pinned by box-car door Interval Prior to Hospitalization—6 hours post-trauma. Extent of Diaphragmatic Tear—12 cm Associated Injuries—laceration of right lobe of liver.

REVIEW OF THE LITERATURE

The English language literature from 1946 through 1957 was reviewed for case reports which gave sufficient data for tabulation. Many of the papers[1, 6, 11, 16, 26, 27, 31] which appeared during this period speak in generalities and do not give enough detail to determine the incidence of associated fractures of the bony pelvis or spine. This is unfortunate, for many of these reports contain the largest number of cases. A recapitulation of the findings in the individual case reports, including our own, is listed in Tables 1

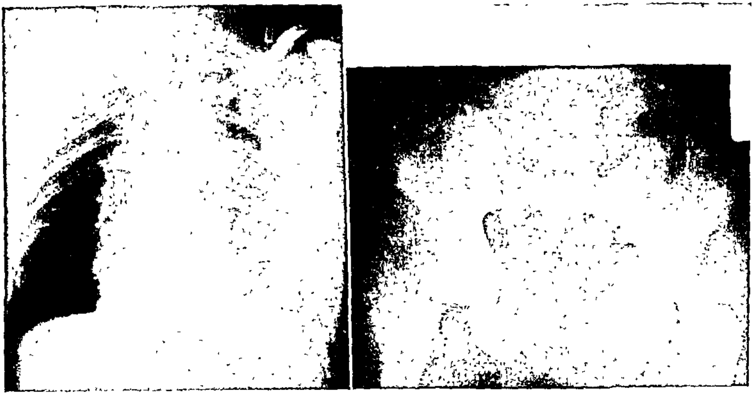

Fig. 5.—Age—43. Year—1957. Etiology—auto crash. Interval Prior to Hospitalization—10 hours post-trauma. Extent of Diaphragmatic Tear—16 cm. Associated Injuries—severe head injury.

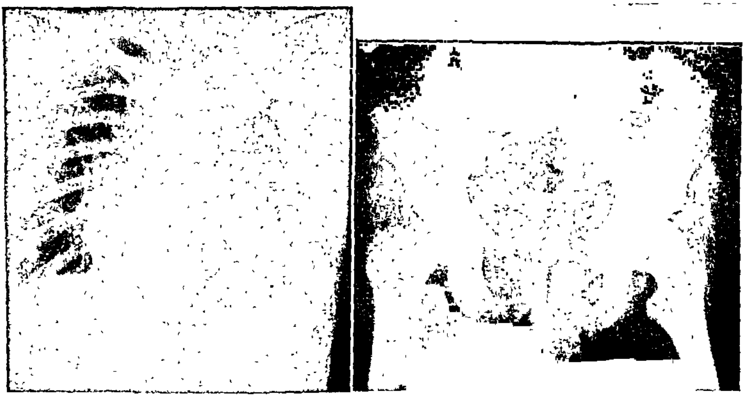

Fig. 6.—Age—24. Year—1957. Etiology—auto crash. Interval Prior to Hospitalization—4 days post-trauma. Extent of Diaphragmatic Tear—12 cm. Associated Injuries—transection of phrenic nerve.

and II. Evans and Simpson,[19] in 1950, described 5 cases of traumatic rupture of the diaphragm associated with a fractured pelvis in 4 of the cases, 1 of which is reported in the above recapitulation. On the other hand, Lam[36] reported, in 1950, that at the Henry Ford Hospital during the previous 10 years an acute traumatic diaphragmatic hernia had been diagnosed only three times, whereas during this same period 206 fractures of the pelvis had been studied. O'Rourke and Jacobson,[45] in 1955, reported that in 7 traumatic diaphragmatic hernias due to indirect trauma, 4 of the patients had an associated fracture of the pelvis. Donald and Clayton,[15] in 1955, stated that a traumatic diaphragmatic hernia should be suspected in all fractures of the lower dorsal and upper lumbar vertebras, particularly when the fracture is due to jackknifing of the patient.

TABLE I. REVIEW OF 99 CASES OF DEHISCENCE OF THE DIAPHRAGM DUE TO NONPENETRATING TRAUMA (1946-1957)

Etiology		
Motor vehicles		77
Automobile accidents	59	
Run over by car	8	
Hit by car	8	
Motorcycle accident	2	
Industrial and agricultural accidents		7
Mining accidents		5
Falls		5
Miscellaneous causes		5
		99
Associated Fractures		
Pelvis	29	
Spine	11	
	40 (36 patients)	
Side of Dehiscence		
Right	15	
Left	85	
	100 (One bilateral lesion)	
Mortality		
16%		

In 77 of the 99 cases, an automobile or motorcycle was involved. Industrial, agricultural, and mining accidents accounted for 12 of the total number. The left diaphragm was involved in 85 patients, the right in 15, including 1 patient who received a bilateral injury.[39] Fractures of the bony pelvis and spine were found in 36 patients, an incidence of 36 per cent. Rib fractures were described in 26 per cent of the cases reported. This may be due to a failure to report isolated rib fractures.

Serious concomitant visceral injury, chiefly to the spleen but involving nearly all of the intraperitoneal organs, was found in 22 patients. In an additional 7 patients, evidence of vascular insufficiency of the bowel was present at operation. Although 5 of these patients were operated upon from 6 months to 23 years following the injury, vascular insufficiency was found in

TABLE II REVIEW OF 99 CASES OF DEHISCENCE OF THE DIAPHRAGM DUE TO NONPENETRATING TRAUMA (1946 1957)

Visceral Injury		
Spleen	14	
Stomach	6	
Liver	2	
Small bowel	1	
Urinary bladder	1	
Kidney	1	
Pancreas	1	
	26	(22 patients)
Vascular Insufficiency		
Stomach	3	
Small bowel	3	
Colon	1	
	7	
Obstruction Without Gangrene		
Stomach	7	
Colon	2	
Small bowel	1	
	10	(9 patients)

2 at 39 hours and 11 days following injury Acute intestinal obstruction without gangrene was found in 9 patients, 1 at 3 days, another at 1 month, and in the remaining 7 from 10 weeks to 17 years following the injury Thus 26 per cent of the patients required early surgical intervention, while 38 patients experienced complications either immediately or later which required emergency operation The over all mortality in the collected series was 16 per cent

SUMMARY AND CONCLUSIONS

1 Nine cases of acute dehiscence of the diaphragm associated with nonpenetrating trauma to the chest or abdomen are reported during the period of 1946 through 1957 Six of these cases had an associated fracture of the pelvis and/or lumbar spine

2 All cases were explored within 5 hours after admission to the hospital In 3 cases, injury to intraperitoneal organs was encountered which necessitated early operative intervention All patients recovered

3 The English language literature was surveyed during the period covered and 99 cases, including the 9 reported in this paper, were encountered The over all mortality rate was 16 per cent In 36 patients a fracture of the pelvis and/or lumbar spine was reported

4 In 26 patients, early surgery was mandatory due to associated intraperitoneal visceral injury, vascular insufficiency of the bowel, or complete gastric or intestinal obstruction without gangrene

5 Early and late complications requiring emergency surgical intervention were found in 38 patients

6 The importance of early diagnosis and early surgical intervention with adequate exploration of the chest and abdomen is stressed

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IVALON AS A CHEST WALL PROSTHESIS

An Eighteen-Month Follow-Up

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FOLLOW-UP reports on new and controversial surgical methods are essential for their final evaluation. A previous report^5 described the use of compressed polyvinyl formol alcohol sponge (Ivalon) as a prosthesis to fill chest wall defects. It is the purpose here to supplement the information presented in the former report, and to describe the condition of 3 such prostheses after time intervals of 16, 17, and 18 months.

CASE REPORTS

CASE 1.—(Two chest wall prostheses.) A 7-month-old, 15 pound Mexican female infant with bilateral tumors of the tenth ribs was operated upon Aug. 1, 1956. The left tumor was completely excised, and the 6 by 7 cm. defect closed with an Ivalon sheet. This sheet was 2 to 3 mm. thick and of tenfold compression. The pathologic report indicated that the tumor was a chondroma showing marked hyaline degeneration. (This procedure was recorded in a previous report.^{5})

The contralateral tumor was completely excised Oct. 3, 1956, leaving a chest wall defect in the costal plane of 6 by 6 cm. A similar sheet of Ivalon was used to repair the defect. The pathologic diagnosis was "rib (resected portion), exostosis (probably osteochondroma)." It was noted that a histologic difference was present in the second lesion as compared to the previously excised lesion. The first specimen contained a large hyalinized fibrotic area which composed the majority of the lesion, whereas the second lesion was largely definite bone.

The baby, at 14 months of age, was admitted Feb. 11, 1957, for treatment of a right middle lobe pneumonia, apparently unrelated to her previous surgery.

When last seen in January, 1958, both operative areas remained well healed (Fig. 1, *A* and *B*). There were indurated areas palpable over the prostheses, but no other evidence of abnormality. Physical development, posture, and the roentgenologic picture were normal (except for the surgical absence of the excised ribs).

CASE 2.—A 22-year-old Negro woman presented herself in clinic in January, 1956, with the complaint of a painful tumefaction over the area of the third left costochondral junction. This had been first noticed about 1 month previously. Chest x-ray studies were normal. The area was explored through a radial incision in the overlying breast on Jan. 18, 1956, and an angulation at the costochondral junction was the only positive finding. A biopsy revealed normal cartilage. The postoperative diagnosis was Tietze's syndrome.

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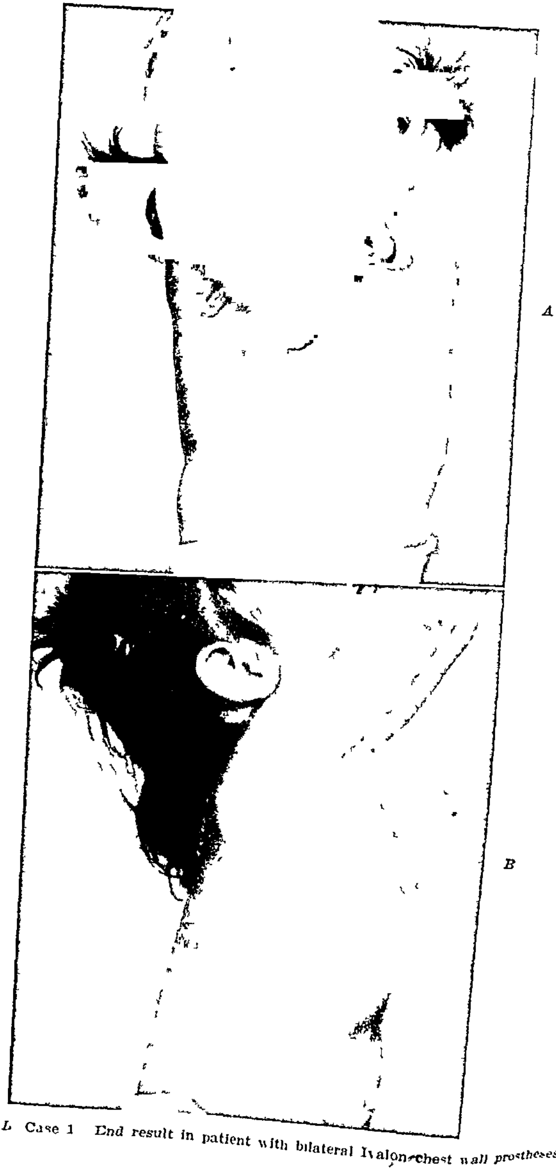

Fig 1—A and B Case 1 End result in patient with bilateral Ivalon chest wall prostheses.

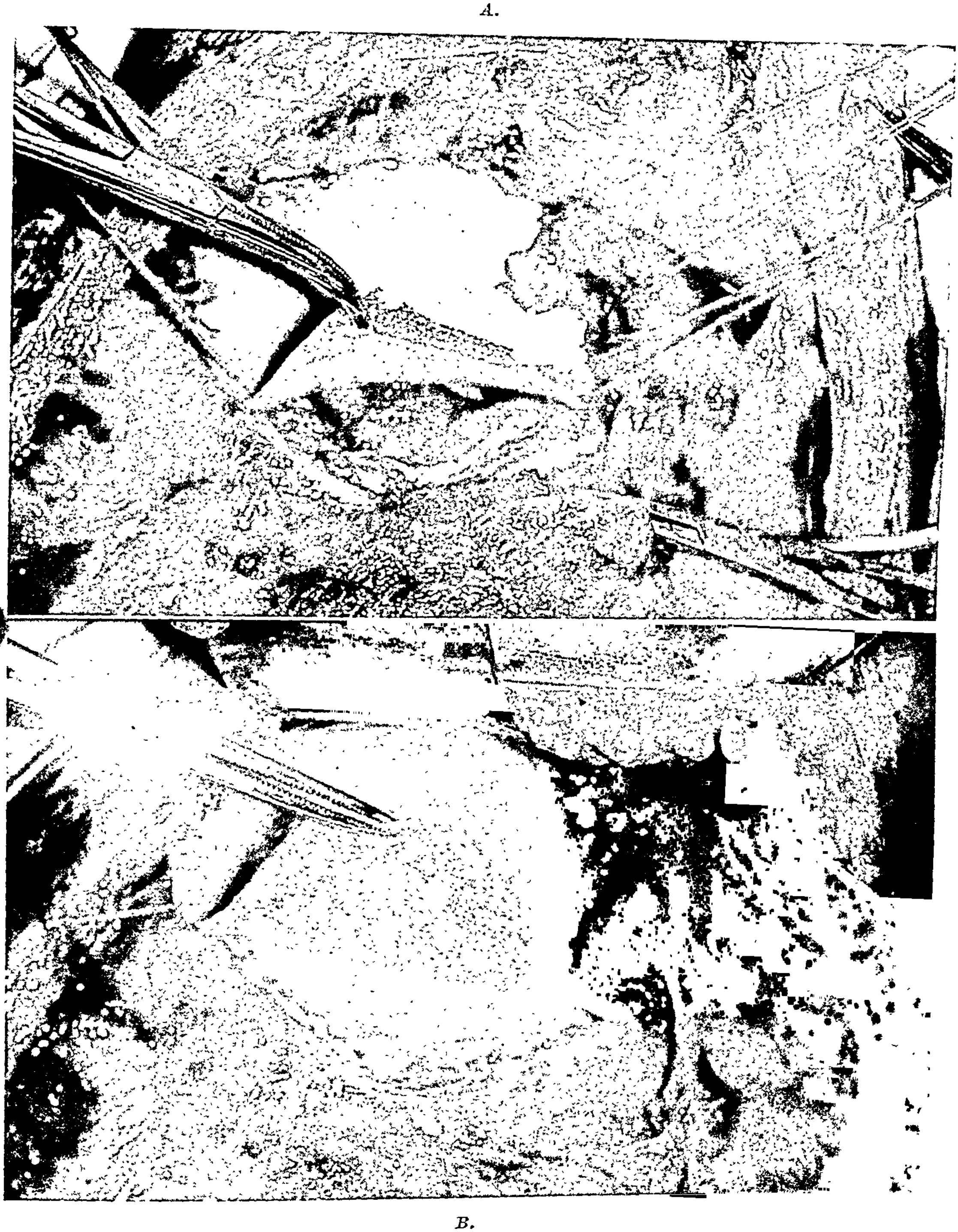

Fig. 2.—*A* and *B*, Case 2. Two superimposed Ivalon sheets are necessary to provide the necessary stability to repair this chest wall defect.

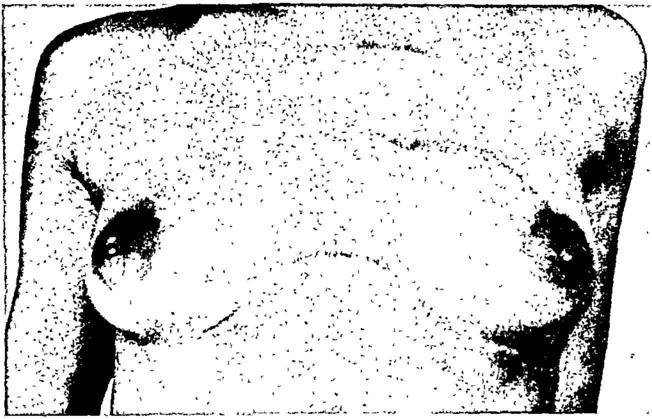

Fig. 3.—End result in Case 2. The area of the Ivalon prosthesis under the superior scar is firm and stable. Note the tumefaction over the second costochondral junction, which appeared about 10 months postoperatively.

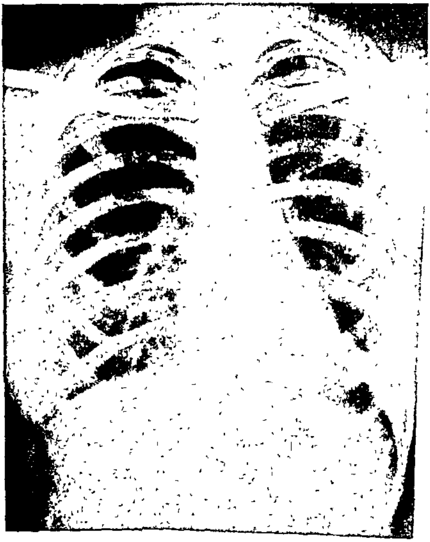

Fig. 4.—X-ray appearance of Case 2, 1 year postoperatively. Note the absence of the inferior portion of the second left rib.

The patient continued to complain of pain in the involved area. Serial palpatory examination suggested enlargement of the tumefaction. Since chondroma could not be ruled out, a complete circumferential excision of the involved area was done on April 27, 1956. The approach was through the old operative scar. Examination of the excised specimen revealed no more than an excessively angulated costochondral junction. The histologic examination revealed normal cartilage and bone.

The patient was completely relieved of pain following surgery. However, about 4 months postoperatively, it became evident that a thoracic wall hernia was rapidly developing. A bulge about 8 cm. in diameter would protrude from the chest wall upon straining or coughing. Local discomfort and anxiety were associated with the lesion.

On Sept. 19, 1956, through a submammary breast-reflecting approach, a 9 cm. chest wall defect was exposed. After placing a pleural drainage tube, an Ivalon sheet 2 to 3 mm. thick (compressed tenfold) was sutured to the periphery of the defect. This sheet exhibited a certain amount of fluctuation with extremes of intrathoracic pressure, so a second similar sheet was sutured into place directly overlying the first (Fig. 2, *A* and *B*). This combined prosthesis showed no protrusion or inversion upon being tested by the anesthetist's applied pressure. The wound was closed without superficial drainage.

The postoperative result was ideal until about July, 1957, when the patient first noticed a protrusion over the second costochondral junction (Fig. 3). This has thus far been asymptomatic.

When last seen in January, 1958, the actual area of the prosthesis seemed quite intact. There was no paradoxical movement, and no protrusion upon coughing. There was no pain or tenderness. X-ray studies (Fig. 4) showed the old partially excised third rib, and some adsorption of the inferior margin of the anterior second rib, in the region where the Ivalon prosthesis was attached. The diagnosis would seem again to be Tietze's syndrome, possibly induced by the attaching of the prosthesis to the area.

DISCUSSION

The characteristics of Ivalon have been recorded elsewhere. It would seem appropriate here to take issue with certain previous statements. Recent evidence would indicate that perhaps Ivalon does not "become strengthened as host tissue grows into its interstices."[6] An unknown percentage of Ivalon arterial grafts have shown thinning, dilatation, aneurysm formation, and rupture.[3] Whether or not this deterioration occurs in sheet grafts such as in these chest wall prostheses is unknown at present. Although there is no evidence indicating that Ivalon is carcinogenic, it would not seem prudent to so state this at present.[1, 2, 5] The variability of tissue reaction to Ivalon would seem to place it in the category of substances which may be either accepted, sequestrated, or rejected by the body. Szilagyi and associates[7] designate these responses as Types I, II, and III reaction, respectively. In our experience, the Type I reaction has been predominant.

Ivalon is so conveniently handled that it seemed appropriate to make an effort to overcome its tendency to weaken within the body. Recently we have incorporated stronger fabrics between two fused sheets of Ivalon. Such a patch has recently been constructed of a Teflon net incorporated within a compressed Ivalon sheet, and used to repair a tangential defect in the intrapericardial ascending aorta.[4] Although the patient is now only 3 months postoperative, certainly this extreme test of strength and host adaptability gives early encouraging results. Perhaps such a modification is also applicable in chest wall prostheses.

SUMMARY

A follow-up report is presented of 3 Ivalon prostheses used to repair chest wall defects. Satisfactory results are evident up to 18 months postoperatively.

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THE USE OF CONVOLUTED DISCS IN THE ROTATING DISC OXYGENATOR

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THE ROTATING disc oxygenator* has been used by us in over 147 patients during total cardiopulmonary bypass.[1] This oxygenator has proved itself to be an effective, safe means of oxygenating blood without the danger of air embolism or excessive destruction of blood elements. In no instance has the oxygenator been a factor in producing complications or mortality. There has been an over-all mortality of 22 per cent which has been reduced to 10 per cent in the last 50 patients.

Although the oxygenating capacity of the 20-inch oxygenator with 94 discs at 120 r.p.m. has appeared adequate in the past to fulfill the oxygen needs during total body perfusion in adults, it has appeared that the oxygenating potential or reserve might be increased for large adults. The arterial oxygen saturation in children with the 13-inch oxygenator with 60 discs has varied from 97 to 103 per cent saturation with oxygen tensions ranging from 120 to 400 mm. Hg. In no instance in this range has there been any evidence of oxygen intoxication.

TABLE I. OXYGEN LEVEL IN ADULTS
(20-INCH OXYGENATOR—94 DISCS—120 R.P.M.)

WEIGHT (LB.)	FLOW RATE C.C./KG./MIN.	C.C. FLOW/MIN.	PER CENT SATURATION (TOWARD END OF PERFUSION)		OXYGEN TENSION
			ARTERIAL	VENOUS	
Flat Discs					
Range 117-172	40-50	2,500-3,300	84-100	45-71	80-180
Average 144	46.1	2,968	92.1	57.2	119
Convoluted Discs					
Range 106-183	40-50	2,250-3,650	91-105	58-94	160-230
Average 127	47	2,800	98	70	200

As noted in Table I, the oxygen saturation and tension level in adults has been lower. The arterial oxygen saturation has ranged from 84 to 100 per cent with an average of 92.1, while the venous saturation ranged from 45 to 71 per cent with an average of 57.2 per cent. Similarly, the oxygen tension has ranged from 80 to 180 mm. Hg, with an average of 119 mm. Hg. Although this level

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*Manufactured by Pemco Corporation, Cleveland, Ohio.

of oxygenation has not shown itself to be deleterious, it has been felt that in very large individuals it would be desirable to have the margin of oxygenating reserve greater.

Initial experiments were hampered in determining the oxygen capacities of larger rotating disc oxygenators because their oxygenating capacities were always greater than the requirements of a laboratory animal. We now employ in the laboratory an oxygenator larger than the one to be tested—referred to as the de-oxygenator—through which nitrous oxide is circulated to de-oxygenate the blood. This is placed in the same circuit as the oxygenator with intervening pumps. The oxygen tension of both the arterial and venous sides of the oxygenator and de-oxygenator are monitored (Fig. 1).

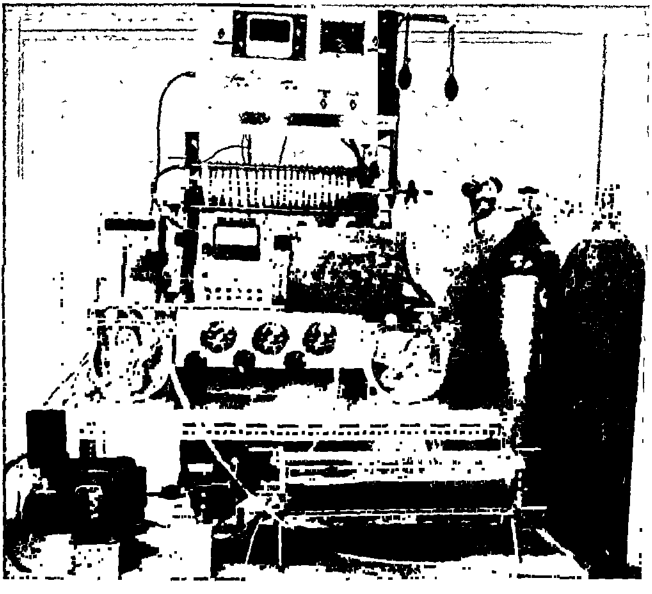


Fig. 1.—Laboratory arrangement for testing the oxygenating capacities of oxygenators by employing a de-oxygenator through which carbon dioxide is circulated to de-oxygenate the blood.

The first and simplest method to increase oxygenating capacity was to increase the oxygenating surface area by increasing the revolutions per minute of the discs from 120 as originally recommended, through varying speeds up to 140 r.p.m. per minute. With the use of the $\frac{3}{16}$-inch spacers between discs, no significant columning of blood occurred with the greater speeds. This maneuver alone in the 20-inch oxygenator containing 94 discs increased the effective oxygenating surface from 148 M.^{2} to 172.2 M.^{2}.

A second method to increase the oxygenating surface was to increase the length of the oxygenator and the number of discs employed. This effects such an increase in oxygenating surface but also increases the amount of the priming volume of the blood, and also has the disadvantage of slowing up the progress of the passage of blood through the oxygenator so that large outputs are more difficult to obtain. This latter factor, however, can again be minimized by increasing the space between the bottom of the cylinder and the rotating discs. However, if this distance is too great, then channeling of blood occurs along the bottom of the cylinder which may not be maximally oxygenated. This principle was utilized in going from the infant oxygenator with 60 discs to the adult one with 94 discs. The length of the oxygenator could undoubtedly be increased to 25 inches with the addition of another 22 discs, which would increase the free oxygenating surface to 183 M.^{2} per minute, at 120 r.p.m. However, it is felt that the present 20-inch oxygenator is probably the optimal length and size.

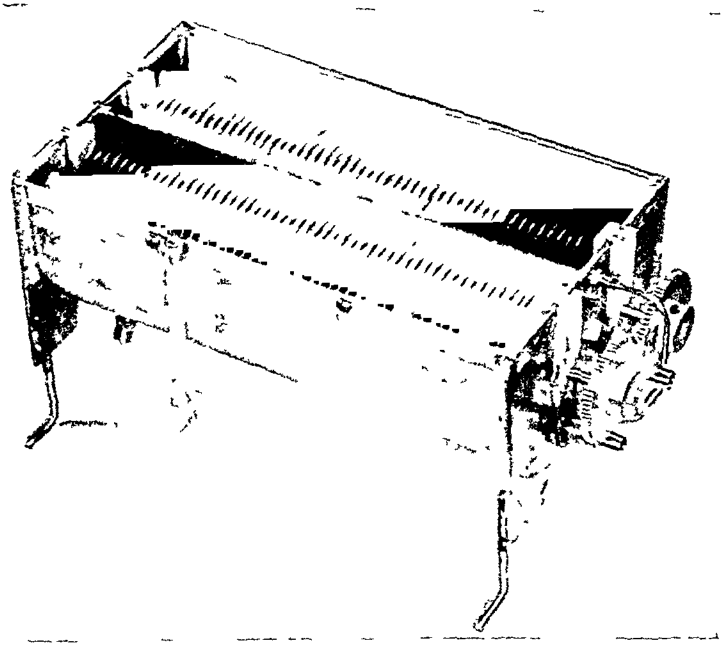
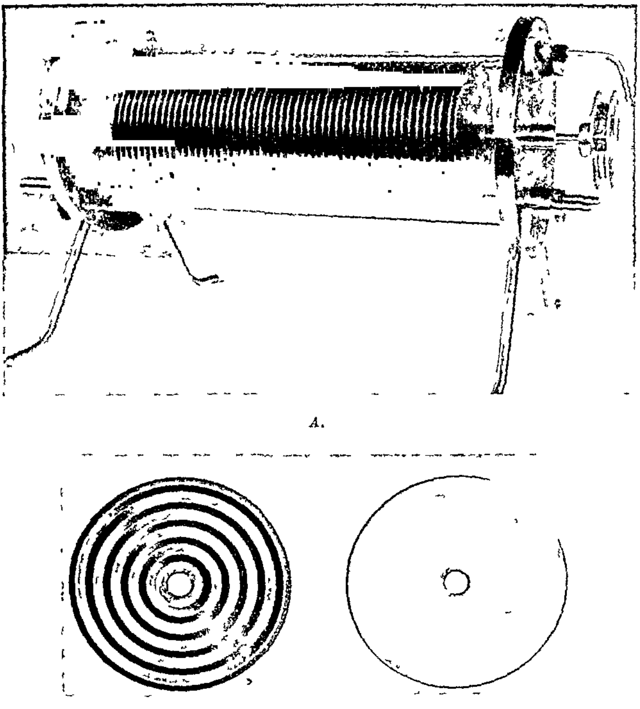


Fig. 2.—The parallel axial oxygenator employed two rows of interdigitating discs.

A third method was to increase the diameter of the discs. An oxygenator was developed in which the transverse diameter of the discs was increased from $4\frac{3}{16}$ inches to $5\frac{47}{64}$ inches. The length of the oxygenator was also increased to 21 inches with 96 discs. This increased the oxygenating surface area to 187 M.^{2}. However, it also increased the priming volume from 2,800 c.c. to 4,000 c.c. which was felt to be unwise. This oxygenator was used in a patient weighing 180 pounds with a tetralogy of Fallot. The arterial oxygen saturation in this patient was 96 per cent with a venous saturation of 62 per cent at a blood flow of 40 c.c. per kilogram per minute and a total flow of 3,300 c.c.

A fourth method was to use two oxygenators in parallel, connected at the ends by Y-connectors. This is also an effective means of increasing the oxygenating capacity of the oxygenator but has the disadvantage of doubling the priming volume and also requiring the operator to watch both oxygenators simultaneously To overcome this latter obstacle, a twin unit was designed utilizing two disc units in parallel which partially interdigitated (Fig. 2)


A.

B

C.

Fig 3 —A, The 20-inch rotating disc oxygenator B, The stainless steel convoluted disc demonstrating the increased surface area C, The original flat disc

Each series of discs revolve upward at the center. A metal container was fashioned as noted, because of the difficulty of moulding a double Pyrex cylinder. This unit has a priming volume of 3,400 c.c, contains two units of 50 and 51 discs each, and has a total oxygenating surface of 157 M.^{2} per minute at 120 r.p m. This is a very effective oxygenator but has the disadvantage of lessened visualization of the oxygenating mechanism by the operator while running, not only because of the metal container but because of the superimposed set of discs

The most effective method so far devised to increase the oxygenating area, without increasing the priming volume or changing the otherwise desirable features, has been the development of convoluted discs (Fig. 3). These discs are stamped with 90-degree impressions in a concentric manner. This increases the oxygenating surface area per disc 41.4 per cent over the flat discs. In the 20-inch adult oxygenator with 94 discs revolving at 120 r.p.m., the effective oxygenating area of the convoluted discs is 208 M.^{2} per minute, as compared to 148 M.^{2} for the flat discs. In the laboratory the oxygenating capacity of the convoluted discs has been found to be 30 per cent greater than the flat discs.

The convoluted discs have now been employed in 10 adult patients (Table I) with arterial oxygen saturation levels approaching 100 per cent and oxygen tensions of 200 or better. It appears to date that this is the most satisfactory method of increasing oxygenating capacity and reserve without losing any of the other desirable features of the original rotating disc oxygenator.

The comparable free area for oxygenation in these various types of oxygenators is noted in Table II. It is seen that the use of convoluted discs not only effectively increases the oxygenating surface over the flat discs in the 20-inch oxygenator by 41.4 per cent but also is the most efficient oxygenating mechanism per 1,000 c.c. volume prime, while retaining the other optimal features of the 20-inch oxygenator. It might appear that convoluted discs would be more traumatic to the blood than flat discs. The factor of hemolysis, which has never been a problem with the use of the rotating disc oxygenator, has even been lowered with convoluted discs and has averaged an increase of only 28 mg. per cent in the patients in whom the convoluted discs have been used.

TABLE II. COMPARABLE FREE OXYGENATING AREA

	PRIME VOLUME IN LITERS	FREE AREA FOR OXYGENATING		FREE AREA PER 1,000 C.C. PRIME VOLUME	
		AT 120 R.P.M.	AT 140 R.P.M.	AT 120 R.P.M.	AT 140 R.P.M.
1. 20-inch oxygenator 94 convoluted discs $4\frac{13}{16}$ inch diam.	2.8	208 M.^{2}/min.*	243.6 M.^{2}/min.	74.0 M.^{2}/ml.	86.0 M.^{2}/ml.
2. 20-inch oxygenator 94 flat discs	2.8	148 M.^{2}/min.	172.2 M.^{2}/min.	52.6 M.^{2}/ml.	61.4 M.^{2}/ml.
3. Parallel axial oxygenator 101 flat discs	3.4	157 M^2/min.	184.0 M.^{2}/min.	52.6 M.^{2}/ml.	61.4 M.^{2}/ml.
4. 21-inch oxygenator 96 flat discs $5\frac{47}{64}$ inch diam.	4.0	187 M.^{2}/min. at 97 r.p.m.†	218.0 M.^{2}/min. at 113 r.p.m.†	46.7 M.^{2}/ml.	54.5 M.^{2}/ml.

*Meters squared.
†Comparable to the greater span of the smaller diameter discs.

The results in the use of the convoluted discs have been so satisfactory that they are now being used routinely in the 13-inch oxygenator for children. It has been possible as a result of their oxygenating efficiency to lower the revolutions per minute and in turn the trauma to the blood when the monitoring of oxygen tension by the oxygen electrode indicates tensions in excess of 200 mm. Hg.

SUMMARY

The maximum oxygenating capacity of the 20 inch rotating disc oxygenator has been discussed in its use in adult patients Various changes have been described in which the free oxygenating surface can be increased without affecting the other desirable features of this oxygenator. Of all such changes tested, the development and use of convoluted discs as described in the text appears to be the most effective means of increasing the oxygenating capacity. This improvement in the oxygenator now adequately fulfills all requirements for oxygen needs in any size individual

ADDENDUM

Over 200 patients have now been operated upon using the rotating disc oxygenator. The opinions relative to this oxygenator are still similar to those expressed in the article.

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MANAGEMENT OF OUTFLOW TRACT TEAR DURING BROCK PROCEDURE FOR PULMONARY VALVAR STENOSIS

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It is not the purpose of this report to debate the relative virtues of the open as opposed to the closed operative approach in the treatment of patients with pulmonic stenosis. Instead, we wish to present one means of salvaging the situation when the posterior wall of the right ventricular outflow tract has been ruptured while utilizing the closed approach.

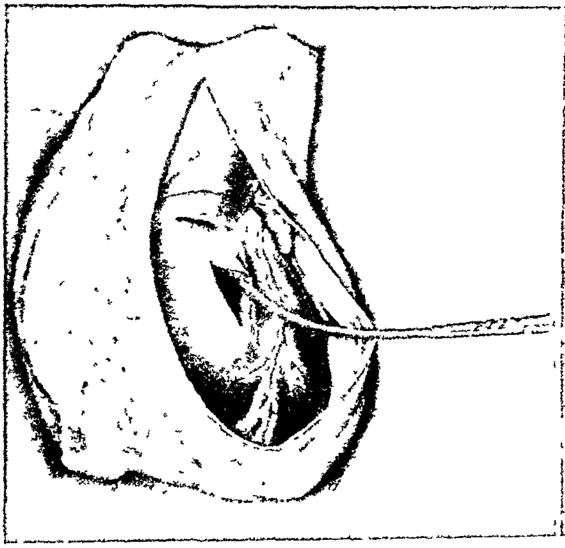

Fig. 1.

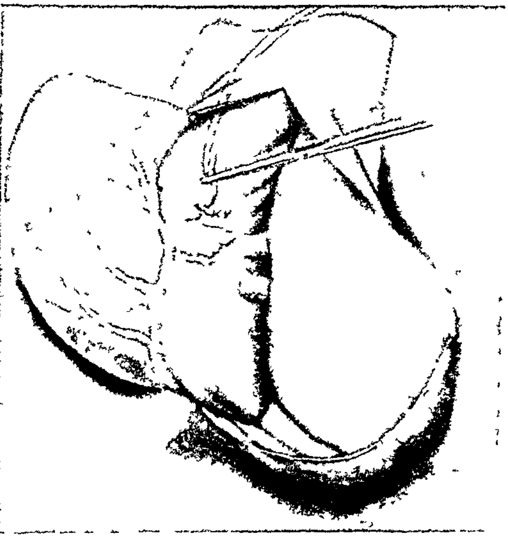

Fig. 2.

Fig. 1.—Production of tear in right ventricular outflow tract.
Fig. 2.—Deliberate dislocation of heart in order to gain exposure for closure of tear.

In any surgical training center, the resident staff learns technical surgery by observing, assisting, and finally doing the various operative procedures. When one takes a resident as far as the "doing" stage with the Brock technique, the resident's first solo into the right ventricular outflow tract may or may not be a smooth one. Approximately once yearly for the past 3 years, this first attempt has resulted in inadvertent puncturing of the relatively inaccessible posterior part of the outflow tract, although it is taught that blind

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instrumentation in the outflow tract is safer when one keeps to the anterior area of the infundibulum and pulmonary artery. In fact, the blunt tip of the bistoury can be palpated through the anterior wall of the main pulmonary artery before it engages with the stenotic orifice in the pulmonary valve. However, if the surgeon encounters resistance in the posterior area of the infundibulum and then unwisely tries to force the instrument past this obstruction, a direct cut or disruptive tear may be produced (Fig. 1). So far, we have found this tear proximal to the pulmonary valve obstruction and hence hemorrhage from the hypertrophied right ventricular cavity has been profuse. Packing the transverse sinus limits, but does not control, the leak. We have found it necessary deliberately to dislocate the heart from the pericardial sac, i.e., to rotate and displace the heart upward and to the right in order to gain access to the tear. The associated hemorrhage, depressed myocardial perfusion and, finally, interference with venous inflow as a result of torsion of the inflow tract can lead to cardiac arrest or ventricular fibrillation. However, only by rotating and displacing the heart can one clearly visualize the rupture in the outflow tract. This hole can then be sutured readily with such exposure (Fig. 2). In one case a portion of the left auricular appendage was used to buttress an especially large and ragged tear. Cardiac resuscitation was possible in all 3 patients after the tear was closed, and the Brock procedure was subsequently completed in each at the same operation. Functional restoration depends upon the relief of the pulmonic stenosis, and survival with relief of symptoms was obtained in all 3 patients.

AN IMPROVED RETRACTOR FOR THE TRANSVERSE STERNOTOMY

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THE ADVENT of open cardiac surgery has made wide exposure of the entire heart a frequent necessity. A bilateral thoracotomy in the area of the fourth and fifth ribs, coupled with a transverse sternotomy, has proved to be a consistently useful incision. The usual "straight-across" incision in the bone has been modified to a sternotomy cut in a "V" with the apex upward. This makes possible a repair with greater lateral stability, and the more firm apposition of the sternal fragments reduces the incidence of malunion. In adult patients, a heavy duty retractor is required with construction directed specifically toward accommodation to this modification of the transverse sternotomy. This need for a sternotomy retractor was recognized by Pontius and Cooley[1] who have designed a fixed-blade retractor for the "straight-across" sternotomy.

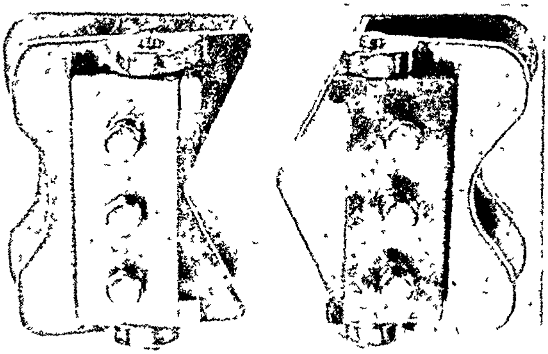

Fig. 1.—A top view of the detachable blades illustrating the V-notch shape and hinge construction for variation in angle.

In designing this retractor the following factors were considered: (1) the need for a strong retractor to achieve adequate spread with a minimum of impedance to exposure, (2) the retractor must be self-retaining, (3) there should be no slippage of the retractor once placed, (4) as the sternum is spread apart the divided ends angulate upward, therefore, the retractor

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From the Department of Surgery and Variety Club Heart Hospital, University of Minnesota Medical School, Minneapolis, Minn.

Supported by research grants from (1) Graduate School, University of Minnesota, (2) Minnesota Heart Association, (3) American Heart Association, (4) Life Insurance Medical Research Fund, and (5) National Heart Institute, Grant No. H-830.

Received for publication April 9, 1958.

blades, unless hinged, will ride upward as well, creating an unwieldly obstacle *to optimum exposure, and (5) the retractor blades should fit the V-notched* sternum.

To encompass these considerations, detachable retractor blades were designed to be adaptable to the Burford-Finochietto self-retaining rib spreader. The upper and lower blades were shaped to fit the respective sides of the V-shaped sternotomy. This gave minimal impingement upon the exposure area.

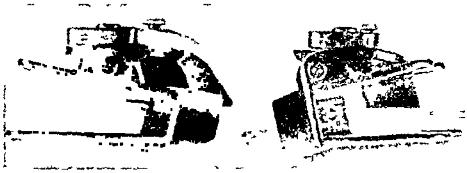

Fig. 2.—A lateral view of the blades showing them attached to the Burford-Finochietto rib spreader. Note the angle of the upper and lower plates of each blade which engage sternal fragments firmly.

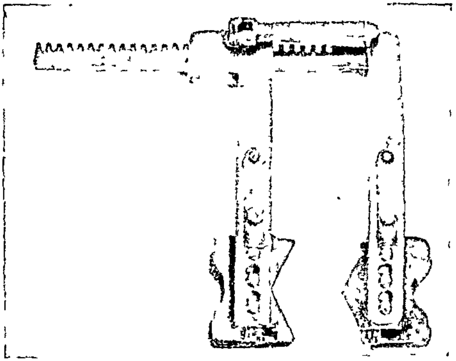

Fig. 3.—An over-all view of the retractor. Its heavy duty construction permits wide exposure with minimal infringement upon working space.

Three sharpened points were placed at the apex of each blade to engage the marrow cavity of the sternum, giving added stability. The blades were hinged in a horizontal plane to accommodate variations in the angulation of the sternal fragments with differences in patient size, incision, and degree of separation of the divided sternal segments. The ability to vary the angle also speeds and facilitates initial placement of the retractor. Stops are placed on the retractor hinges to prevent angulation beyond 40 degrees. The upper and lower plates of each blade are spaced to grasp *the rib cage and sternum firmly* [illegible]vent vertical displacement. The blades were made from he[illegible] st[illegible]eel.

These retractor blades have been used with excellent success in our adult patients undergoing cardiac surgery via a bilateral sternum-transecting thoracotomy. In this experience one of the principal improvements in design over pre-existing, self-retaining sternal retractors has been the hinging of the blades which facilitates exposure by allowing the arms and body of the retractor to lie flat and out of the way as the sternal segments are spread apart.

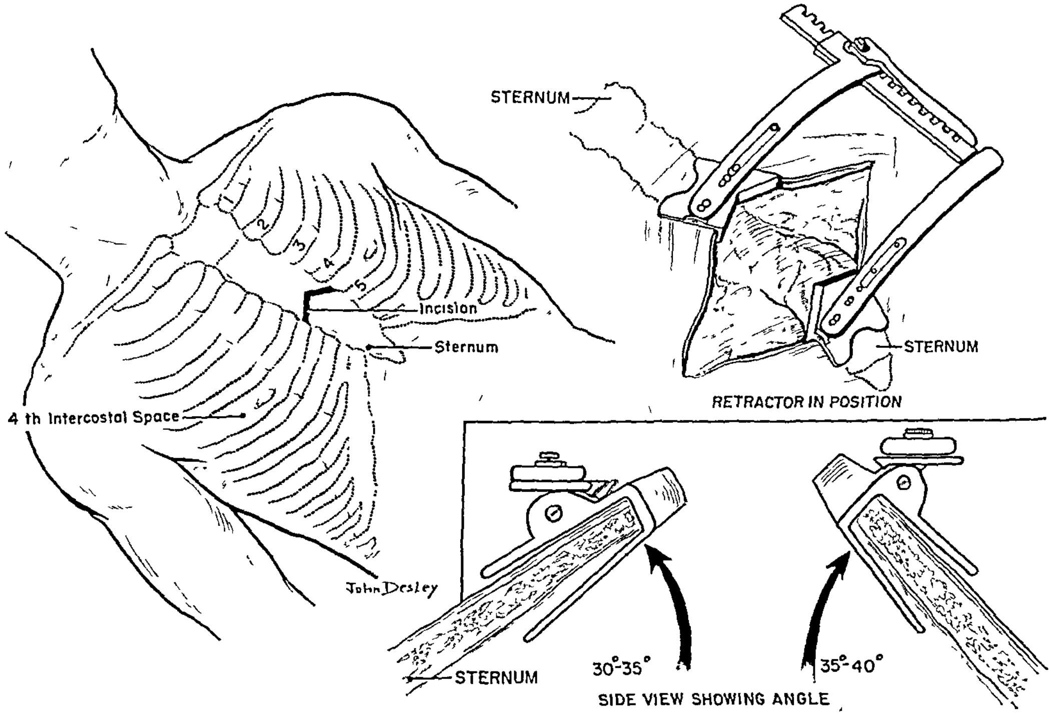

Fig. 4.—The type of "V" sternotomy is illustrated. The wide retraction and fitting of the retractor to the sternal fragments allows maximum exposure. Hinging of the blades allows the body of the retractor to lie flat and out of the way despite variable angulation of the sternal fragments.

REFERENCE

1. Pontius, R. G., and Cooley, D. A.: A Modified Sternal Retractor for Bilateral Anterior Thoracotomy, J. Thoracic Surg. 34: 135-136, 1957.

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-ninth Annual Meeting of the American Association for Thoracic Surgery will be held April 21, 22, and 23, 1959, in Los Angeles, California. Headquarters will be the Hotel Statler.

Requests for Hotel Reservations

These should be mailed directly to Mr. William Truman, Reservation Manager, Hotel Statler, Los Angeles, California. Please mention this Association, the type of accommodation desired, the date and approximate hour of arrival and departure. If accommodations are desired elsewhere in Los Angeles, please communicate directly with the hotel of your choice.

Material for the Program

Scientific Papers.—Abstracts of all papers proposed for presentation at the 1959 meeting *must be received on or before November 15, 1958,* otherwise they will not be considered by the Program Committee. These should be labeled "For Thoracic Surgery Forum" or "For Regular Program" depending upon the nature of the subject matter, in the same manner as in previous years. They should contain from 200 to 250 words that accurately reflect the content of the completed paper.

Six, repeat, six clearly legible copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, Suite 308, Carondelet Building, 7730 Carondelet Avenue, St. Louis 5, Missouri.

Essayists selected for the program are reminded that papers presented at the meeting *must* be handed to the secretary *immediately* after their presentation. If they are not ready at that time there is a chance that they will not be published in The Journal of Thoracic Surgery.

Motion Picture Session.—Plans are again being made to show suitable motion pictures selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. John C. Jones, Suite 509, 1136 West Sixth Street, Los Angeles 17, California, *before November 15, 1958.*

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee *not later than November 15, 1958,* otherwise the application will be deferred for consideration until the 1960 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signature on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. Duane Carr
Chairman of the Membership Committee
899 Madison Avenue
Memphis 3, Tennessee

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Chairman of the Membership Committee should their applicants be held over for reconsideration a *second year.*

Evarts A. Graham

The Journal of
Thoracic
Surgery

VOLUME 36
SEPTEMBER 1958
NUMBER 3

Original Communications

EVARTS AMBROSE GRAHAM (1883-1957)

Eulogy

Tom Burford

On March 4, 1957, the spirit of Evarts Ambrose Graham passed quietly into that select Valhalla that shelters the shades of the truly great. Death with tragic irony resulted from bronchogenic carcinoma, a disease he had studied for over a quarter of a century, and a malady which he had battled so valiantly and successfully to conquer and control in others. Insidious in onset and hopeless at the time of discovery, his disease progressed with merciful rapidity. Aware from the beginning of the diagnosis and its terrible portent, he faced the issue with awe-inspiring equanimity. Not once did he manifest the slightest degree of bitterness or self-pity. With serene objectivity he sublimated all concern for self to an amazingly critical contemplation of cancer in general, and of lung cancer in Evarts Graham in particular. He was much more concerned by the fact that he, a nonsmoker for seven years, in developing the disease might have invalidated his own etiological contentions than he was by the prospect of dying.

Born in Chicago on March 19, 1883, he attended public schools and the Lewis Institute. He graduated from Princeton in 1904 where early in his undergraduate period he decided to devote his life to a surgical career. It was at Princeton that he stated his oft-quoted determination "To do major surgery, to engage in research work, and to have a clinic of younger men who would be interested in studying and developing ideas." This cogent capsule contains the essence of the great surgical saga that was the life

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Portions of this Eulogy were presented before the Society of Clinical
York in October, 1957, but not published.

of Evarts Graham. All of the fine panegyrics that will be penned at the end can add little to what he so confidently said of himself at the beginning. In 1907 he received his M.D. from Rush Medical College where his father, Dr. David W. Graham, was a teacher of surgery. Following graduation he interned at the Presbyterian Hospital in Chicago for one year. He spent the following year as a Fellow in Pathology at Rush. Dissatisfied with the traditional surgical training of that era, he did special work in chemistry and physiology. Working with Woodyatt, Carlson, Wells, and others, he acquired a broad background in the basic disciplines which did much to inspire and shape his later career. It was during this period that he met Helen Tredway, a graduate student in chemistry. They were married in 1916. Dame fortune smiled often on Evarts Graham, but never more warmly than when this gracious and brilliant lady agreed to share his life. She created the cultured orderly home so necessary to the success of a busy scientist and surgeon on the one hand, and on the other carved out for herself a distinguished career in teaching and research.

In 1915 he entered private practice. He rarely spoke of this experience and it is noteworthy that he was careful to omit it from his Curriculum Vitae. However, with his infallible gift of serendipity, even this experience was to prove significant. First-hand contact with unnecesary surgery, ghost surgery and fee-splitting shocked and infuriated him. Not long before his death in discussing his early years with me he said of this awakening, ''I resolved then that if I ever had a chance to do something about these things that I would.'' Those who were privileged to serve with him on the Board of Regents of the American College of Surgeons know how effectively he kept that resolution.

In 1918 he entered the United States Army with the rank of Captain. Later in the same year he was appointed to the Empyema Commission and promoted to the rank of Major. It was while a member of the Empyema Commission that he did his brilliant work on the dynamics of intrapleural pressures which led to a safe and rational approach to the problem of intrapleural sepsis. He was then sent to France as commanding officer of the 34th Evacuation Hospital. On his return to the States he was sought out by Philip Shaffer, Canby Robinson, and Eugene Opie and offered the Bixby Chair of Surgery at the Washington University School of Medicine in St. Louis, which he accepted. It is a matter of record that he took over his duties as professor of surgery wearing his army uniform. It cannot be verified, however, as one disgruntled, and perhaps bruised, contemporary contended, that he also wore spurs. In St. Louis he joined with Shaffer, Erlanger, Robinson, Marriott, Opie, and others in the exciting adventure of creating a great medical school. In a short time he was the acknowledged leader of this distinguished group, and the school's international reputation today is due more to the efforts of Evarts Graham than to any other member of the faculty. During his tenure the surgical service was a world-renowned Mecca.

In 1922 he first conceived the idea that visualization of the gall bladder might be possible. His broad background in chemistry made him aware that the chlorinated phenolphthaleins are excreted almost exclusively in bile. By substituting radiopaque atoms to these compounds he hypothesized that visualization of the biliary tract should be possible. The epochal success of his ensuing experiments and the success of cholecystography are known to all. This, in my opinion, was his greatest scientific contribution, and was, as Alfred Blalock has stated, worth a Nobel Prize. On April 5, 1933, he made one of the great technical contributions of all times when he performed the first successful one-stage pneumonectomy for bronchogenic carcinoma. To some it has seemed strange that Graham, with his emphasis on basic disciplines, should consider a purely technical feat his greatest contribution. To understand this apparent paradox it is necesary to have known the man. He came to St. Louis noted only for productive research and was contemptuously dubbed the "Mouse Surgeon" by the entrenched, but now forgotten, old guard. He neither forgot nor forgave this indignity. In addition, he was always mindful that careful, bloodless techniques were not his forte. How natural then that the fait accompli of so magnificent a technical feat should symbolize to him a major victory—a triumph in the only area of his many endeavors where he ever felt the slightest sense of inadequacy.

Each year brought increasing prestige and heavier burdens of work and responsibility. His capacity for sustained painstaking effort was prodigious. This attribute plus his uncompromising integrity and his supreme self-confidence were the keystones, in my opinion, of his character and career.

Throughout his notable career he was untiring in his efforts to improve the standards of medical care and medical education and to this end he unhesitatingly accepted appointments to many national committees. He served for fourteen years as a member of the Medical Fellowship Board of the National Research Council. From 1940 to 1946 he was Chairman of the Committee on Surgery of the National Research Council. In 1944 and 1945 he was a member of the Commission on Hospital Care. In 1952 he was appointed a member of the President's Commission on the Health Needs of the Nation In 1953 and 1954 he served on the Medical Task Force of the first Hoover Commission. In each instance he served with the courage and effectiveness that characterized every phase of his career.

Honors and distinctions of every kind were showered on Evarts Graham. Recipient of fourteen honorary degrees and many distinctions, he was repeatedly honored at home and abroad. No American surgeon has ever so completely won the esteem and affection of Colleagues in South America, [illegible] Continent, and in England in particular. Even after retirement the pilgrimage of notables from the four corners of the world continued to his office—a [illegible] to the acknowledged Dean of World Surgery.

He was elected directly to active membership in this Association [illegible] third annual meeting in New Orleans in 1920, becoming the eighty-[illegible] ber. In 1928 he was elected President. In 1931 with the establishment [illegible] JOURNAL OF THORACIC SURGERY he became the first editor [illegible] post he held with conspicuous success until his death.

senior member and, in 1955, on the motion of Leo Eloesser, became the twenty-fifth honorary member of the Association. While not one of the founding fathers, his contributions to this body and his influence in shaping the destiny of this organization rank second to none. By honoring Evarts Graham, the American Association for Thoracic Surgery acknowledges its indebtedness to its greatest member and thereby does honor unto itself.

Retirement came to Graham in 1951. Whatever academic retirement may mean to lesser men, it was to him a challenge and a new beginning. He returned to the laboratory with the zest of a young graduate student, and began a large-scale investigative program. His studies ranged from the experimental production of cancer in mice with the tars from cigarette smoke to an effort to determine why the antlers of the deer family are regenerated so rapidly. Outside the laboratory his interests seemed to widen rather than contract.

From 1951 to 1954 he was Chairman of the Board of Regents of the American College of Surgeons, and in 1955 was elected President of the Sixteenth Congress of the International Society of Surgery.

He was among the first to become intelligently alarmed by the problem of radioactive fall-out. His reaction was characteristic. He moved directly into the national political arena, and it was due in no small measure to the efforts of Graham and his friend Norman Cousins that Adlai Stevenson was persuaded to make a campaign issue of Strontium 90, and nuclear testing.

Socially and politically, Graham was an enlightened and often militant liberal—a born crusader. Emotionally and ethically he was an unreformed Victorian. To him privilege and power implied stern responsibility. "He knew no motive but interest—no criterion but success." It was thus inevitable that his rise to high position should foster within him a sense of noblesse oblige, and that this should make men of little discernment often falsely call him cold and autocratic and even ruthless. His biographer will have no difficulty in showing up the superficiality of these evaluations and will find an abundance of warm color, generous tones, and even humble shades from which to paint a true picture of Graham the man.

Gordon Taylor could well have been speaking of Graham when he said of Moynihan in the first Leeds Lecture, "Those who have been reckoned great in surgery must of necessity be supremely skilled in the craftsmanship of our profession; they must, by reason of the initiation of some novel and successful system of treatment, have conferred untold blessings on mankind; their work must have illuminated the dark, mysterious chasms in our knowledge of disease. It is necessary that they should have inspired their pupils and their surgical brethren with their own ideals, and should have inaugurated or sponsored some policy which has advanced the science of surgery. Their prospects of pre-eminence . . . are perhaps enhanced, if they are accounted 'Men of Affairs,' and if they command success in their everyday relationships and dealings with those who are not necessarily linked by close ties with our profession."

By these and by all criteria Evarts Graham will be reckoned among the greatest.

PRESIDENTIAL ADDRESS
A CASE REPORT AND MISCELLANEOUS COMMENTS

Brian Blades, M.D., Washington, D.C.

My first and pleasant obligation is to express profound appreciation to the members of The American Association for Thoracic Surgery. And of equal importance, to thank the Officers and committee members whose efforts determine the success or failure of our meeting. Particular gratitude is deserved by the Secretary, Dr. Hiram Langston, and Miss Ada Hanvey, Administrative Assistant.

The honor of being President of this Association is impossible to define. The endeavors of those whom I have just cited have made most of the duties and responsibilities of the office easy. There is, however, one notable exception, the preparation and presentation of the presidential address.

Mild plagiarism was first considered. A careful review of my predecessors' contributions, however, made this impractical. Their subjects have consisted of dissertations on philosophical, educational, and historical matters or reports of brilliant surgical achievements or research endeavors. It became apparent I had neither information nor the ability to imitate their examples.

In desperation I have decided to present a case report as the principal feature of this address.

The unusual history, methods of diagnosis and, finally, the surgical management will, I hope, justify the review of a clinical problem in a Presidential Address.

Following the case report there will be a few miscellaneous and probably confusing comments.

From the Department of Surgery, The George Washington University, Washington, D. C.

Presented at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

CASE REPORT*
BARNES HOSPITAL

History No. 37532

Name Gilmore, James Lee (Dr.) Nee

Address 1331 Inverness Pittsburg Pennsylvania

Age (1st Admission) 49 Years [✓ Married], Single, Divorced Separated

Sex Male Race White Nativity Pennsylvania Occupation Physician

Nearest Relative or Friend Marjorie Gilmore How Related Wife

Address Same

Family Physician

Address

Recommending Physician Dr. W. T. Mitchell, Jr. O.P.D. No.

Address Pittsburg Pennsylvania

Staff Physician Dr. Graham Dr. Arbuckle Dr. Singer

Remarks

ADM. DATE	SERV.	DISCH. DATE	DIAGNOSIS & OPERATION	CONDITION AT DISCHARGE
27 Feb 33	Surg Med	5 Mar 33	Tumor of Bronchus, Uncertified. (Lt. upper lobe) Artificial Pneumothorax. (Carcinoma?) 3-1-33 Bronchoscopy.	Not Improved
9 Mar 33	Surg	9 Mar 33	Tumor of Bronchus, Uncertified. (Carcinoma?)	Not Treated
13 Mar 33	Med Surg	24 Mar 33	Carcinoma of Bronchus. 3-14-33 Bronchoscopy. Excision of Tissue of Bronchus for Diagnosis. 3-21-33 Bronchoscopy.	Not Treated
4 Apr 33	Surg	18 Jun 33	Carcinoma of Bronchus. (Lt. upper lobe) Carcinoma of Lung. (Squamous cell) 4-5-33 Pneumectomy. (Total) (Left) Blood Transfusion. Thoracoplasty. (Partial) (Left) 4-19-33 Thoracostomy. (Closed drainagé) (Left) 5-13-33 Thoracostomy. (for empyema) 5-22-33 Thoracoplasty. (Partial) (Left)	Improved

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*The case report is a facsimile of the original records including misspelled words.

Abstract of the record of Dr James L Gilmore Age 48 yrs

Admitted	Discharged
2 27 33	3 5 33
3 9 33	3 9 33
3 13 33	3 21 33
4 4 33	6 18 33

Patient enters hospital with a history of

1 Repeated attacks of cough and fever with pain in the chest
2 General lassitude
3 Easily fatigued
4 Loss of weight and inability to gain weight

} 7 months duration

In January 1929 patient developed pneumonia of the right lower lobe It spread from this location and involved the entire lung Convalescence was delayed for several weeks and terminated by his "raising some pus "

In July 1932 he experienced a general malaise with chilly sensation and a fever of 104 Nothing found on P X WBC 17,000 On Aug 11th an x ray revealed a fan shaped shadow with the base outward, in the region of the left axilla By Aug 20th his symptoms had subsided and the x ray shadow had become smaller On Oct 7th he experienced a repetition of his former symptoms with return of the former x ray shadow This subsided in a few days only to recur again about Oct 20th At this time there was some dullness and a diagnosis of (interlobar empyema) lung abscess was made On attempting to aspirate it (Dec 5, 1932) a pneumothorax developed subsequent to which his symptoms improved He experienced some pain in the left chest following production of pneumothorax (not much pain and no bloody sputum at any time) The pneumothorax was continued and was improved until 10 days before admission (2 17 33) when he had a recurrence of fever and discomfort, etc Examination revealed a man of medium build with suggestion of loss of weight and having a pale pasty complexion Did not look acutely ill The left chest moved less than the right and B S were diminished or absent X rays of the chest showed the left upper lobe atelectatic with pneumothorax present (The lower lobe seemed fully expanded and adherent to the chest wall) RBC 4,800,000, WBC 11,500, HB 85%

In view of the patient's history, PX, and x ray findings, a tentative diagnosis of bronchial obstruction by a tumor was made

Bronchography substantiated the diagnosis of bronchial obstruction of the left upper lobe

Bronchoscopy 3 1 33 revealed tissue not unlike the appearance of granulation tissue, closing off the lt upper bronchus Bronchoscopy repeated on 3 14 33 and 3 21 33 Biopsy taken revealed squamous cell carcinoma of the bronchus

Patient took microscopic slides to home pathologist to have verified

Patient was readmitted 4 4 33 for lobectomy At the operation (4 5 33) the tumor and suppurative process was found such that it was necessary to remove the entire left lung Many adhesions made this somewhat difficult Seven ribs were also removed, 3 to 9 inclusively Left the operating room in good condition (had received glucose acacia and some blood) Closed drainage yielded several (800 to 1000 cc) of serosanguinous exudate for 48 hours There was little P O reaction except for some dyspnea especially on exertion Considerable deep seated pain was *experienced at times but was fairly well* controlled Some infection of the unobliterated portion of the left chest occurred on the 8th or 9th P O day which was drained by a stab wound posteriorly This failed to function after 2 weeks (during which time patient was being prepared for removal of the remaining 1st and 2nd ribs to obliterate the remaining) so a [illegible] drain anteriorly through the 1st interspace. The 1st and 2nd ribs were removed on 5-22-33, with little post-operative reaction. His pain then completely subsided and within 3 weeks all wounds were healed. His strength gradually increased, as well as the use of his left arm. He gained in weight and his color improved remarkably. Appetite was good and on discharge, 6-18-33, he was looking quite healthy, much better than he had for many months previously. His only complaint was some dyspnea on exertion and this was not marked. His respiratory function improved much after his heart had become compensated to his being up and about. He had been walking about for 2 weeks at time of discharge from hospital. Vital capacity on admission 3,500; at discharge 1,650. At time of discharge his blood showed 5,100,000 RBC., 8,500 WBC., and 90% HB. On discharge, his ECG. was practically normal.

Weight on admission 4-4-33 145 lbs.. On May 21, 1933, his weight was 130 lbs.. On June 14, 121½ lbs., June 18, 122½ lbs., June 28, 126 lbs..

Operative Report

Anesthetic Remarks: Uneventful. Pulse good volume. Color good. Glucose given when B.P. fell. Pt. responded at completion of operation. Blood transfusion was given.
Dictation: Dr. Graham.

An incision was made over the 6th rib; the rib was removed from the transverse process to the anterior axillary line. The 7th rib was also removed in the same way and the intercostal bundle was excised. The pleura was opened and the upper lobe was found to be atelectatic. Several masses could be felt within it suggestive of infiltration with carcinoma. Although the apex of the lung was free from adhesions there were many other adhesions between the lung and the chest wall. There were particularly dense ashesions between the upper lobe and pericardium, and also posteriorly between the upper lobe and the parietal pleura. The lower lobe was adherent everywhere to the chest wall. In the upper part of the upper lobe several firm nodules were felt which were suggestive of carcinomatous metastases. In attempting to separate the upper lobe from the lower lobe, it was found that the interlobar fissure was not fully developed. There were also some nodules in the upper part of the lower lobe which were suspicious of carcinomatous involvement. It was felt that not only would it be very difficult to remove the upper lobe alone, but also that in doing so some of the cancer would be left behind. Consequently it was decided to remove the entire left lung. After separating the adhesions, most of which required clamping and cutting followed by ligation, the pedicle was freed and a small catheter was tightly secured around it. It seemed preferable to use the soft pressure of a rubber catheter rather than a crushing clamp for this purpose, in order to preserve the blood supply as much as possible to the end of the stump of the bronchus. The idea behind this was to encourage healing of the bronchial stump as much as possible. Distal to the catheter two clamps were placed on the entire pedicle and an incision was made between them thereby cutting away the entire lung. After cutting away the lung, the open stump of the bronchus was cauterized thoroughly with the actual cautery and then swabbed with 25% silver nitrate solution. The stump was then transfixed with a needle carrying a double thread of #2 chromic catgut. This was tied securely around the whole pedicle. Another double ligature of #2 chromic catgut was placed in a position slightly distal to the first ligature, and finally a third ligature of the same sort was applied. The catheter was then removed and no bleeding from the stump occured. The open end of the stump of the bronchus was slightly less than one inch from the bifurcation of the trachea. The aorta was plainly visible immediately posterior to the stump of the left bronchus. Because the entire lung had been removed there was no tissue available for covering over the stump of the bronchus. Two enlarged mediastinal glands, which could be seen immediately below the bifurcation of the trachea, were removed for microscopic examination. These, however, seemed soft and evidently did not contain any cancer. Because the patient's condition seemed excellent, and because it was felt desirable to obliterate the pleural space as much as possible, additional ribs were removed from the transverse processes to the anterior axillary line The ribs removed were the 4th, 5th, 6th, 7th, 8th, 9th and 10th Thru a small stab wound a small catheter was inserted below the line of incision and carried into the pleura cavity just below the stump of the pedicle This catheter fitted tightly so that no leakage of air at all occured around it The wound was then closed in layers and it was noted that the soft tissues collapsed readily into the pleural cavity No attempt was made to suture the parietal pleura together The 6th and 7th muscle bundles had been removed in order to give exposure, but the rest of the muscle bundles were not cut away The patient was given a blood transfusion in the operating room and left the operating room with blood pressure and pulse the same as they had been at the beginning of the operation The rubber catheter was connected with a longer rubber tube which was brought down to the level of some boric acid solution in a bottle in order to give air tight drainage

SURGICAL PATHOLOGY BARNES HOSPITAL

Name	Gilmore, Dr J L	Register No	89475	Age	48
Address		Ward		Date	4 5 33 (11 11 48)
Surgeon	Dr Graham	Specimen No	21246		

Gross Pathology (11 11 48) The gross specimen consists of the entire left lung which is received in Kaiserling fixative The entire lower section through the entire lung at 2 to 3 cm intervals has been made There is a tumor mass ulcerating into the upper lobe bronchus near the hilum which on cut section appears to be well delineated and measures 3 cm in its greatest diameter Distal to this tumor in the upper lobe there are numerous pinpoint abscesses in the lung parenchyma Over the posterolateral apical region of the upper lobe there is a markedly thickened pleura which appears to have a portion of the parietal pleura attached to it The lower lobe appears to be essentially normal without abscesses, obstruction or abnormalities of the pleural surfaces On gross examination the superior interlobar bronchial node which is immediately adjacent to the tumor appears to be directly involved in the process There are several other nodes about the upper lobe bronchus which do not appear to be involved in the tumor process Several small nodes about the lower lobe bronchus are likewise negative grossly Many black and white and colored photographs were taken of the fixed gross specimen The following additional sections are taken

A_X—a section of the tumor to show its entire extent
A—4 to 5 additional sections of the tumor
B_1—6 lymph nodes from about the upper lobe bronchus
B_1—a section from the thickened pleural surface at the posterior apex of the upper lobe
D_1—3 nodes from about the lower lobe bronchus Jar IV (Black)

Microscopic Pathology The surface of the tumor as it projected into the bronchus showed a fairly well differentiated pattern with numerous epithelial pearls The tumor extended into the lung parenchyma destroying bronchial cartilage and invading contiguous lymph nodes In the deeper areas of the neoplasm it was extremely undifferentiated with practically no keratinization and with numerous mitotic figures In one area of the neoplasm, as it arose from the bronchus, there was squamous metaplasia and epidermoid carcinoma in situ Further nodes, 11 in number, showed no evidence of tumor

Diagnosis Lung, bronchus, left, upper — Epidermoid carcinoma, grade III
Lymph nodes, regional — Epidermoid carcinoma, grade III, invasive
Lymph nodes, regional — Hyperplasia, 11/11
Lung — Bronchial pulmonary suppuration with multiple small abscesses

Lauren V Ackerman, M D

It is important to note that the review of the tissue by Dr Lauren Ackerman in 1948 established that the lesion was an invasive epidermoid carcinoma Moreover, there was involvement of a lymph node

Two postoperative notes by our distinguished colleague, Dr. William Adams, then a Fellow in Surgery, are worth recording.

4-6-33 "Patient quite comfortable unless he moves. He had no M.S. since 8 A.M. Has
3:15 not voided since operation. B.P. remaining at 120/ No cyanosis or dyspnea. Pulse
Adams steady. Drained about 800 cc through catheter during interval from 12 M yesterday
until 11 A.M. today. Little drainage since. Temp. down to 37.2° this noon. O_2 tank
to be kept in room and O_2 tent available in case of emergency."

4-18-33 "Patient's temp. has risen to 39.7° tonight. Pulse 134. R 32. No cyanosis.
Adams States he is having some respiratory difficulty. Coughing if attempts to lie on rt.
side or on talking. Dr. Graham notified of condition. Given Aspirin 10 gr. and
Codeine 1 gr. to lower temp."

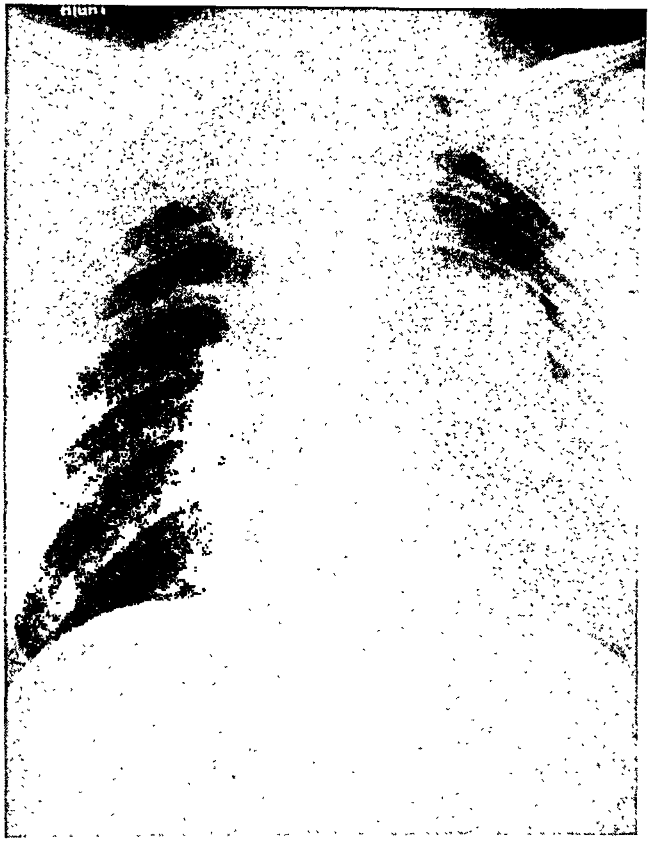

Fig. 1.—Roentgenogram showing pneumothorax and Lipiodol bronchogram. The pneumothorax was accidentally induced when a thoracentesis was performed.

4-19-33 "Patient's general condition about the same this A.M. except less respiratory dis-
Adams tress, less cough, and less pain since midnight. Fluoroscopy reveals similar condition as that seen yesterday morning. Under general anesthesia a #14 catheter was inserted through a trocar into cavity at level of 4th dor. vert. just medial to scapula. 150 cc of thin redish-brown pus was removed. Open drainage established."

It appears the bronchus began to leak 13 days after the operation. Certainly no one could accuse the staff of prescribing too much medication.

A few years after the first successful pneumonectomy for carcinoma of the lung, rumors were circulated that the lesion was not really a carcinoma, but an adenoma The amazing longevity of misinformation has been demonstrated because to this day one occasionally hears this misstatement repeated It is appropriate, therefore to show a photograph of the gross specimen and the photomicrograph (Figs 1 2, and 3)

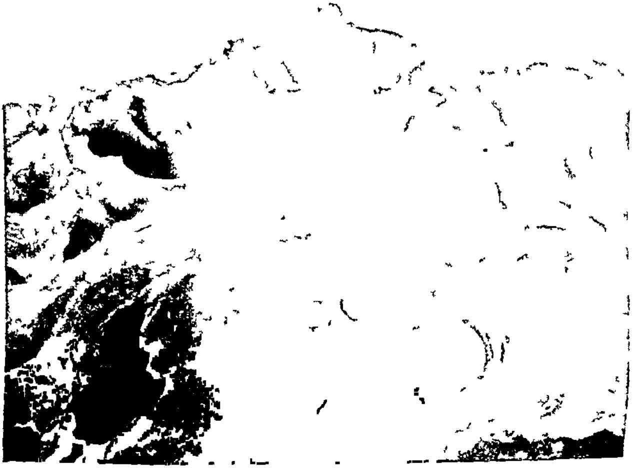

Fig 2 —The gross specimen showing a bronchogenic carcinoma in the left upper lobe

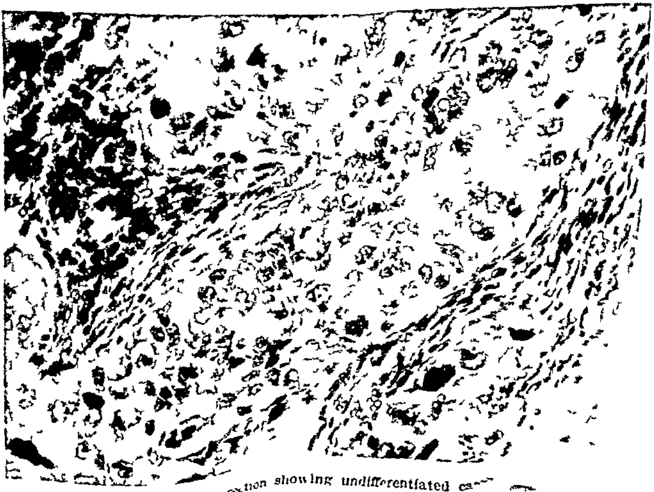

Fig 3 —Microscopic section showing undifferentiated ca

While the patient was recovering from the pneumonectomy, thoracoplasties, and thoracostomies, the meeting of The American Association for Thoracic Surgery was held on May 9, 10, and 11, 1933. Before attending in absentia the Sixteenth Annual Meeting of the Association in Washington, D. C. it is important to conclude the case report. The patient is vigorous, living and well twenty-five years after the removal of the left lung.

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Officers

President, George P. Muller, Philadelphia
Vice President, George J. Heuer, New York City
Secretary, Duff S. Allen, St. Louis
Treasurer, Edward D. Churchill, Boston
Editor, Evarts A. Graham, St. Louis

Council

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Edward S. Welles, Saranac Lake

The American Association for Thoracic Surgery
Washington, D. C., May 9, 10, 11, 1933
Hotel Headquarters — The Willard Hotel

Program

Tuesday, May 9

9:00 A.M. National Museum Building.

1. Business Meeting of the Association.
2. The Results of Phrenic Nerve Operations in 225 Cases With a Discussion of the Technique of the Operations.
   Dr. H. Ryerson Decker, Pittsburgh.
3. An Estimate of the Value of Phrenic Nerve Interruption for Phthisis Based on 654 Cases.
   Dr. John Alexander and Dr. Lawrence Nehil, Ann Arbor.
4. Experimental Study of the Effect of Phrenicectomy on Cough.
   Dr. Herbert A. Carlson, Minneapolis, Dr. Harry C. Ballon, Montreal, Dr. Hugh M. Wilson and Dr. Evarts A. Graham, St. Louis.
5. Thoracoplasty.
   Dr. E. J. O'Brien, Detroit.
6. The Operative Mortality From Thoracoplasty in Pulmonary Tuberculosis. Analysis of 6 Fatal Cases.
   Dr. H. L. Beye, Iowa City.
7. A Study of 150 Cases of Thoracoplasty for Pulmonary Tuberculosis During the Past Two Years — Reflection of Technique and Results.
   Dr. Pol. N. Coryllos, New York City.
8. Bronchogenic Carcinoma. Special Reference to Its Classification, Prognosis and Treatment.
   Dr. Louis H. Clerf and Dr. B. L. Crawford, Philadelphia.

1:00 P.M.

1. Collapse Therapy and the Ambulatory Patient.
   Dr. J. A. Myers, Minneapolis.

2 The Future Surgical Status of the Collapse Therapy Patient
Dr T J Kinsella, Oak Terrace, Minn
3 Pneumocavernolysis in the Treatment *of Pulmonary Tuberculosis With Cavitation*
Dr Harold Neuhof, New York City
4 Non Penetrating Wounds of the Heart The Cardiac Manifestations Brought About by Acute Peripheral Compression
Dr Claude S Beck and Dr Ernest Bright, Cleveland
5 Removal of Needle From the Heart With Electrocardiographic Studies Before, During, and After Operation
Dr Francis Scrimger, Montreal
6 The Diagnosis and Treatment of Encapsulated Empyemata
Dr W A Hudson Detroit
7 Moving picture study of the treatment of acute empyema
Dr Jos Gale Madison
8 Moving picture study *of the treatment of acute empyema*
Dr Ralph B Bettman, Chicago

Wednesday, May 10

9 00 A M

1 Executive Meeting of the Association
2 President's Address
Dr George P Muller Philadelphia
3 Address on Lung Abscess and Pleural Effusion
Dr Marc Iselin Paris France (By special invitation)
4 Pneumonectomy for Sarcoma of Lung in a Tuberculous Patient
Dr Howard Lilienthal, New York City
5 *Dermoids of the Mediastinum*
Dr Carl A Hedblom, Chicago
6 Intrathoracic Teratomas
Dr S W Harrington, Rochester, Minn
7 Esophagectomy for Cancer of the Upper Esophagus With Lessons Derived From an Operative Failure
Dr P E Truesdale, Fall River, Mass
8 Experiences With Oleothorax Treatment
Dr John N Hayes and Dr *Lawrason Brown*, Saranac Lake

1 00 P M

1 Active Contractility of the Bronchopulmonary Smooth Muscle as *Demonstrated by* Electrobronchographic Records
Dr Ethan F Butler, Elmira, N Y
2 An Experimental Study of the Reactions *of the Pleura to the Bacillus of Tuberculosis*
Dr W S Lemon, Rochester, Minn
3 Effects of Laparotomy and Abdominal Distention on the Lung *Volume*
Dr Edward D Churchill Dr H Beecher, Dr H H Bradshaw, and Dr G E Lindskog, Boston
4 The Treatment of Traumatic Haemothorax An *Experimental and Clinical Study*
Dr D C Elkin and Dr J C Sandison, Atlanta
5 *Physiological Determinants in* Surgery for Relief of Cardiac *Pain*
Dr Peter Heinbecker, St Louis
6 The Tensile Strength of the Paralyzed Diaphragm
Dr Richard H Meade Jr, Philadelphia
7 Extreme Compre*ssion* and Cirrhosis of the *Lung A Preliminary Experiment*
Dr C M Van Allen Peiping, China

8 00 P M PRESIDENT'S BANQUET

Thursday, May 11

9:00 A.M.

1. Bronchiectasis.
   Dr. James A. Miller, New York City.
2. Selective Surgical Collapse for Lung Abscess.
   Dr. Richard H. Overholt, Boston.
3. Fixation of Chest Lesions With Subsequent Compression.
   Dr. W. P. Herbert, Asheville.
4. Oidiomycosis of the Lungs.
   Dr. David T. Smith, Durham, N. C.
5. Experimental Pulmonary Lesions of Aspergillus Niger: Superimposition of This Fungus *on Experimental Pulmonary* Tuberculosis.
   Dr. Norman Bethune, Montreal.
6. Suture of the Lung.
   Dr. Frank S. Dolley, Los Angeles.
7. Intrapleural Pneumolysis. A Critical Review.
   Dr. Julian A. Moore, Asheville.

The following officers were elected for 1934:

President	Dr. George J. Heuer	New York City.
Vice President	Dr. John Alexander	Ann Arbor, Mich.
Secretary	Dr. Duff S. Allen	St. Louis, Mo.
Treasurer	Dr. Edward D. Churchill	Boston, Mass.
Editor	Dr. Evarts A. Graham	St. Louis, Mo.

The following were advanced from associate to active membership:

Dr. I. A. Bigger	Charlottesville, Va.
Dr. Alfred Blalock	Nashville, Tenn.
Dr. Peter Heinbecker	St. Louis, Mo.
Dr. W. A. Hudson	Detroit, Mich.
Dr. Richmond L. Moore	Asheville, N. C.
Dr. LeRoy S. Peters	Albuquerque, N. M.
Dr. David T. Smith	Durham, N. C.
Dr. Owen H. Wangensteen	Minneapolis, Minn.

The following were elected to associate membership:

Dr. William Adams	Chicago, Ill.
Dr. Clyde Allen	Detroit, Mich.
Dr. J. B. Amberson	New York City
Dr. Marr Bisaillon	Portland, Oregon
Dr. Maurice Fisher	Rochester, N. Y.
Dr. Wallace Frank	Louisville, Ky.
Dr. Cameron Haight	Ann Arbor, Mich.
Dr. George F. Herben	Loomis, N. Y.
Dr. Chevalier Jackson, Jr.	Philadelphia, Pa.
Dr. Foster Murray	Brooklyn, N. Y.
Dr. J. W. Nixon	San Antonio, Texas
Dr. George Ornstein	New York, N. Y.
Dr. John Powers	Boston, Mass.
Dr. Leo Rigler	Minneapolis, Minn.
Dr. Willard Van Hazel	Chicago, Ill.

Of the thirty-five scientific papers presented twenty-five years ago more than a third were on various aspects of the treatment of tuberculosis Interest in the heart was manifested by three important papers There was only one presentation concerning bronchogenic carcinoma and two on *mediastinal tumors* The subjects of empyema and lung abscess had their share of attention and it appears that one half day was devoted to experimental studies in much the same way that time is set aside for the forum in our present programs

The esophagus rated only one paper with lessons reported from a failure of esophagectomy for carcinoma of the upper third of the esophagus History has a strange way of repeating itself.

There were sixty-seven members present at the meeting twenty-five years ago, fifty-three active, twelve associate, and two senior members, a sharp contrast to the Thirty-Seventh Annual Meeting of the Association in Chicago at which there were more than one thousand registrations

The meeting in Washington was held in a small lecture room of the Smithsonian Museum The place of the meeting was determined by the Congress of American Physicians and Surgeons This was the last time The American Association for Thoracic Surgery met as a component member of the Congress *

The Program Committee this year received one hundred and fifty-four abstracts for consideration Enough outstanding papers were available to fill three full programs One might long for the good old days, but a quarter of a century ago the trials of the program committee were expressed by Dr Muller in his presidential address

> "This year for the first time your Program Committee has been embarrassed by the quantity of material offered and found it difficult to follow the rule of accepting all offerings from members It seems to me that in the future, committees will find it expedient to select those papers which offer new thoughts or are sufficiently controversial to excite discussion "

One paper deserves special attention Not for the presentation itself, but because of the battle of semantics which it precipitated I refer to the paper "Pneumonectomy for Sarcoma of the Lung in a Tuberculous Patient" by Dr. Howard Lilienthal

It is safe to assume that Dr Graham was elated about the patient back in St Louis who had survived the removal of an entire lung It is not surprising, therefore, for him to discuss Dr Lilienthal's pneumonectomy case in a confident way and to describe his now convalescent patient and the details of the case in a scholarly manner The trespass into the field of etymology, however, was most unfortunate

A portion of Dr Graham's discussion is as follows

> Dr. Evarts A Graham (St Louis) —I was much interested in this case of Dr. Lilienthal because he operated upon his case just a short time before I performed a complete

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*By authority of Dr Ethan Flagg Butler's "little black book" Dr Duff Allen, the Secretary could not be present because Mrs Allen was having a baby Dr Butler was drafted to serve as secretary pneumectomy. In my case, however, fortunately the result was successful. I do not call it pneumonectomy, as Dr. Lilienthal does, because I have the support of the Oxford dictionary and various other dictionaries to call it pneumectomy instead of pneumonectomy.

The Oxford dictionary and other references did not impress Dr. Pol. Coryllos who not only was a Greek, but knew the Greek language well.

> Dr. Pol. N. Coryllos (New York).—(Illustrating on blackboard.) First a point of etymology. I agree with Dr. Lilienthal that the correct Greek term for excision of the lung is ‘‘pneumonectomy’’ and not ‘‘pneumectomy’’ as proposed by Dr. Graham. The lung in Greek is *πνεύμων-ονος*, whereas *πνεῦμα-ατος* means air or spirit. The second part of the term, ‘‘*εχτομὴ*’’ (excision) indicates the action exerted upon the lung, therefore the latter must be placed in the genitive (*πνεύμονος*) the radical of which is *πνεύμον-* so that the composed word will be ‘‘pneumonectomy.’’ ‘‘Pneumectomy’’ on the contrary means ‘‘resection of air,’’ and if correctly constructed should be pneumatectomy. It is according to the same rules that are constructed the terms gastrectomy, ureterostomy, salpingectomy, otorhinolaryngology, etc. I hope that this literary digression will help to settle that question.

This must have been a bitter pill since Dr. Graham was a real stickler on diction, grammar, and particularly superior about his knowledge of word roots.

It is impossible to determine accurately the exact number of surgeons who were engaged in a significant amount of thoracic surgery twenty-five years ago. Certainly no more than a hundred in the United States and Canada, probably considerably less. Only a few limited their work to the chest and most of them were prominent general surgeons who were interested in developing a new field. There were a few physicians with little or no surgical training attempting to do chest wall operations on patients in the tuberculosis sanatoriums.

Opportunities for training in thoracic surgery were limited. In most instances the program was integrated with general surgery with sometimes the addition of fellows who might spend an extra year or two in clinical work and research projects connected with thoracic surgery. A few exceptions, however, were developing. In January of 1933, Dr. John Alexander established at the University of Michigan a training program in thoracic surgery with a minimum appointment of two years' duration. Others, including Dr. E. J. O'Brien, Dr. Pol. Coryllos, and Dr. Louis Davidson established residencies devoted exclusively to surgery of the chest.

Two philosophies were beginning to develop. One, a concept of exclusive specialization in thoracic surgery. The second and more popular then, additional training for the surgeon who might also operate in the chest, but remain principally in general surgery.

Twenty-five years ago only a small minority accepted the feasibility of specialization. The field seemed too small; the patients were poor physical and financial risks; and economic suicide was often predicted for those foolish enough to desert general surgery.

Reliable data concerning the number of surgeons in this country limiting their practice to thoracic surgery are not available. It has been estimated that in the neighborhood of two hundred and fifty do so. The remainder of those now certified by the Board of Thoracic Surgery do not After twenty five years the differences of opinion concerning specialization remain, but in different proportions

It is apparent, however, that the dire financial disasters predicted for the specialists were unwarranted An important factor, of course, has been the thoracic surgeon's successful wrestling match with nose and throat specialists for the control of endoscopes

Originally the members of our Association were not receptive to establishing a board of Thoracic Surgery It was first discussed in 1936 and a committee appointed to study the question In 1937 the committee's opinion was that there was no need for certification of thoracic surgeons by a separate Board at that time

In 1945 a second committee was appointed and made its report in 1946 A recommendation was adopted favoring the formation of a Board of Thoracic Surgery as a subsidiary of the American Board of Surgery A plan of organization was established in 1948 by the Eggers Committee And the Board of Thoracic Surgery was incorporated under the laws of the State of Michigan on Aug 31, 1950, as a subsidiary of the American Board of Surgery

There are now two hundred and twenty eight founder members, and in the decade of existence five hundred and thirty four candidates have been certified by examination

A total of seven hundred and sixty two surgeons have a certificate stating they are properly qualified to operate upon the chest of their fellow man The recent crop of thoracic surgeons has been abundant Two hundred and fifty nine have been certified in the past 3 years It might appear that the principle of supply and demand is being violated

The establishment of first the American Board of Surgery and later its subsidiary, the Board of Thoracic Surgery, stimulated surgical segregation Influences on rank and assignment during World War II gave a final and mighty emphasis to Board certification

Practically all surgical specialties were originally developed by general surgeons, but in most instances have become distinct and separate fields of endeavor as the specialty develops

Incredibly complete severance with one of the oldest surgical specialties has been so radical that surgeons certified by other Boards must relinquish the previously conferred sheepskin to become eligible for certification

Fortunately, there is little chance of surgical contamination in this particular specialty since only one year of internship is required before the special training

The tendency to drift from old patterns of emphasis on general surg is shown by the requirements of other Boards For example, the Neur cal Board requires only one year of surgical internship preliminary to t in the specialty The Board of Orthopedic Surgery specifies a year o ship and one year of general surgical residency as a preliminary

The Board of Thoracic Surgery is a subsidiary of the Surgery Total dependence on general surgery is estab the definition of subsidiary—meaning: furnishing aid, auxiliary, tributary, as a capacity; secondary.

No Board has more rigid requirements. Certification by the American Board of Surgery and an additional two years of training.

Our rigid standards resulted from the philosophy that all engaged in thoracic surgery must first be trained in general surgery. Certainly one of the reasons for this particular emphasis was to discourage physicians who entered the field via the chest wall route without previous experience in surgery. Time and the combination of antibiotics with the modern surgical treatment of tuberculosis have practically eliminated this group. Probably another factor was the failure of other specialty Boards to require adequate basic surgical training.

Fortunately the original plan of two written and two oral examinations has been condensed with the elimination of the written examination in thoracic surgery. The first part of the general surgical Board, however, now includes a certain prescribed percentage of questions relating to thoracic surgery. This change, however, has created problems for the young surgeon who has little or no contact with thoracic surgery during the general surgical training.

It is easy to comment that in a properly integrated service the trainee should have sufficient background to answer correctly the questions on thoracic surgery. In many instances, however, this is simply not the case. Depending upon the pattern of training the general major and the thoracic major might find this examination quite difficult.

There are now eighty-nine hospitals approved for training in thoracic surgery. One wonders if there are really eighty-nine institutions in existence in our country with sufficiently varied clinical material and available teachers. This is a particularly pertinent question in regard to surgery of the heart and great vessels.

Neither the American Board of Surgery nor the Board of Thoracic Surgery attempt to define independently an acceptable training program. Residencies in surgery are judged by a conference committee consisting of representatives of the Council of Medical Education of the American Medical Association, the American College of Surgeons, and the American Board of Surgery. Moreover, the American Board of Surgery and its subsidiary, the Thoracic Board have made it clear that they are not concerned with special privileges or recognition their diplomates may obtain by virtue of certification. This is in sharp contrast to many specialty groups who make their own ground rules for training programs and emoluments for their certificates.

Thoracic surgery is now a distinct specialty and it is safe to predict it will become even more so. And, it makes little difference how each of us in this Association feels about it. The public and the nonsurgical segment of the medical profession have nurtured specialists and, in fact, demand them.

Otherwise intelligent members of our profession are very apt to classify a colleague as a Board man or not a Board man. The layman has a similar approach with different terminology. The surgeon is a heart man, lung man, or some kind of man whom they associate with the repair or eradication of various vital or semivital organs.

It would be difficult for surgeons who have fulfilled the qualifications for certification in thoracic surgery to lose interest in general surgery. Once, however, they are labeled they are often confined to a single field of endeavor. This is particularly true of those in private practice. A small minority of surgeons in full time clinics and medical schools are not quite so limited, but even in these institutions the trend is toward regional specializaton as far as operating is concerned.

Although the battle for various organs continues, the chest man has been gaining ground, or perhaps better stated, not infrequently successfully raids outside of his designated body cavity.

On the left he can slip through the diaphragm for spleens or stomachs without treaty violation serious enough to cause a major battle. And on the other front, a thyroid gland which isn't well above the sternal notch is fair game.

Conversely, surgeons now designated as generalists are fighting valiantly on two fronts. They have been pushed down on the left flank by the chest specialist and forced upward on the other major battle-field by the colon-rectal specialist who also has been commissioned by his Board to engage in this war. The war with the neurosurgeons was lost years ago. For the most part bones have been taken away by the orthopedist, and even burns by the plastic surgeon. The general surgeon still controls the right flank of liver and gall bladder and the middleground, but his supply lines are thin.

This half facetious, but not far from the truth, description of the state of surgical affairs may create serious problems for the young surgeon.

In the five to seven years after graduation from medical school this now not so young surgeon, trained in general and thoracic surgery, leaves the institutional nest—not because he is incompetent or not wanted—the nest is full, and there is the possibility he has had about all of the nest he can tolerate. He searches and finds a community he admires and in which there is a reasonable chance to make a living. He may then find it is expedient or totally necessary to pattern his practice by default.

If in the community there are three well-established, fairly young thoracic surgeons and the majority of the general surgeons are senile or well on the way—general it will be, or the converse may be true. In either event there has been a waste of talent, energy, and money.

Prerequisite training in general surgery before specialization I sincerely hope will continue. And it is proper to suggest that other specialties would profit by following this example.

It appears, however, present standards or, better stated, rules for training are not realistic and perhaps untenable.

For example, is it really necessary in every case to spend four years following internship in general surgery before training in thoracic surgery? Is it reasonable to prescribe a six months' minimum credit for the [illegible] in basic the definition of subsidiary—meaning: furnishing aid, auxiliary, tributary, as a capacity; secondary.

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For example, is it really necessary in every case to spend four years following internship in general surgery before training in thoracic surgery? Is it reasonable to prescribe a six months' minimum credit for the study in sciences? For the interested student the study of physiology, chemistry, or almost any science might result in a potential contributor to the progress of surgery. Conversely, it would be utterly ridiculous to require all, including the uninterested to follow the same pattern of postgraduate education.

These questions are easy to ask, but extremely difficult to answer in a specific way. It is suggested, however, there be fewer rules and that more attention be given to quality of training rather than quantity in terms of years.

A quarter of a century has passed since the pneumonectomy of our case report was performed by the man whose memory we honor today. During this time, thoracic surgery has progressed from a faltering, dangerous formative stage to a recognized surgical specialty.

More than any other organization in the world our Association will influence the trends of the next twenty-five years. It is appropriate then, to ask ourselves just what have we done and more important, what are we going to do.

Thanks are expressed to Remington Rand, Inc., St. Louis, for providing photostats of the original records which had been placed on microfilm.

I am deeply indebted to Doctors Ackerman, Bradley, Burford, and Moyer who made records and the photographs of the specimen available, and to Dr. James Gilmore who gave permission to review the case report.

FURTHER STUDIES IN THE SURGICAL MANAGEMENT OF CARCINOMA OF THE LUNG

A Further Study of the Cases Treated at the Massachusetts General Hospital From 1950 to 1957

Edward D. Churchill, M.D., Richard H. Sweet, M.D., J. Gordon Scannell, M.D., and Earle W. Wilkins, Jr., M.D. (by invitation), Boston, Mass.

EIGHT years have elapsed since the previous report of the surgical management of primary carcinoma of the lung at the Massachusetts General Hospital. That report[1] included all cases seen in the years 1930 to 1950 with follow-up data on all resections carried out prior to January, 1948. The present study brings up to date the results of surgical management of cancer of the lung at the same hospital by adding all cases seen in the period January, 1950, to January, 1957, with follow-up information on *all* resections performed before January, 1956. The follow-up data have been divided into 2 groups identified as "present series" which includes all resections carried out between January, 1948, and January, 1956, and "original series." The latter includes all cases of resections prior to 1948. The two groups are considered together as a "total" series of 341 cases followed to January, 1958, representing all patients undergoing resection for carcinoma of the lung at the Massachusetts General Hospital from 1933 to 1956. Follow-up data are available on all patients.

The present study, as the previous one, includes all patients admitted to the general hospital wards as well as those admitted to the private divisions. Since the operations have been carried out by a great number of individuals on both the visiting and resident staffs, it would be unwarranted to assume a standardized technique or extent of resection. In general, the principles of operation were those outlined in the previous report. Lobectomy, with removal of all gross evidence of disease, was considered reasonable when there was evidence of diminished pulmonary or cardiac reserve, when uncertainty of the diagnosis existed and the lesion could be totally excised by lobectomy, when the lesion was small, peripheral and without evidence of lymph node

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From the General Surgical Services of the Massachusetts General Hospital and the Department of Surgery of the Harvard Medical School, Boston, Mass.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

extension, and when the carcinoma had extended beyond surgical bounds but the bulk of the primary tumor could be removed by lobectomy with the hope of relieving symptoms. Again, it should be emphasized that the majority of lobectomies were carried out not merely as a local excision of a primary growth, but as a complete dissection of an anatomic unit of the lung to include the adjacent lymph nodes. Similarly, pneumonectomy included as extensive dissection of adjacent nodes as the operator deemed advisable, with or without intrapericardial division of the hilar structures as the situation demanded. In the present study no effort has been made to separate "radical" as opposed to "simple" pneumonectomy or lobectomy nor to correct for those resections undertaken when it may have been the estimate of the surgeon that the disease had extended beyond the limits of extirpation.

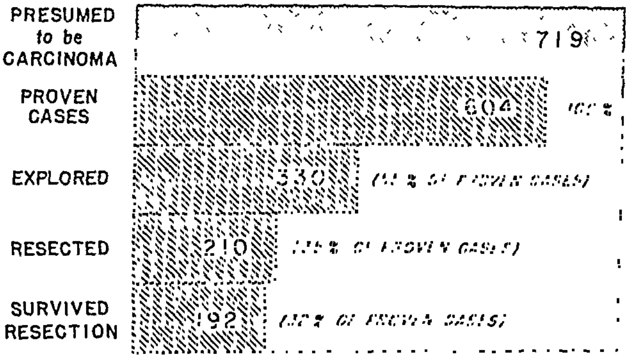

Fig. 1.—Primary carcinoma of the lung, 1950 to 1957.

Specifically excluded are all cases of bronchial adenoma, either the carcinoid or cylindroma types, all carcinomas that might reasonably be considered metastatic, and all cases of pulmonary alveolar adenomatosis (alveolar cell or bronchiolar carcinoma). Although the latter form an extremely interesting group of cases, their nature is sufficiently debatable to warrant exclusion from the group commonly termed bronchogenic carcinoma.

Between Jan. 1, 1950, and Jan. 1, 1957, a clinical diagnosis of carcinoma of the lung was entered in the records of 719 patients (Fig. 1). In 604 of these, the clinical diagnosis was verified by histologic means. Of the 604 proved cases, 330 or 55 per cent came to thoracotomy. In 210 of these (35 per cent of the proved, 64 per cent of the explored), resection of the tumor was possible by pneumonectomy or lobectomy. One hundred and ninety-two patients survived resection and left the hospital alive (32 per cent of the proved cases). Since the 5-year cumulative survival rate for this period was approximately 30 per cent, it can be assumed that 63 patients survived or could be expected to survive 5 years (10.4 per cent of the proved cases). When compared to our earlier report these figures represent some improvement. The corresponding percentages in the 1930-1950 patients are: proved cases 681, explored 294 (43 per cent); resected 171 (25 per cent of proved); survived resection 137 (20 per cent).

It is hoped, but by no means certain, that the increase in the number of resectable tumors reflects an increasing awareness by the medical community of the constructive role of surgery in the management of carcinoma of the lung and the value of early diagnosis. In type and duration of symptoms the patients of the present series differ very little from the former series or from the many other large series recorded in the literature. There is, however, one new and clinically identifiable group, namely, the "survey" case, a designation we have applied to the individual whose pulmonary cancer was discovered as a result of investigation initiated by the presence of a suspicious shadow in a chest x-ray film taken in the course of a survey, routine physical examination, or study of an apparently unrelated medical or surgical problem.

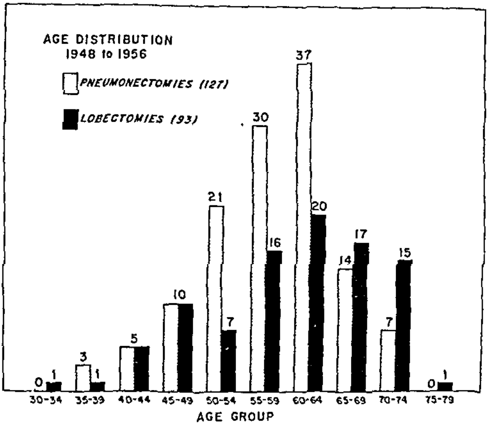

Fig. 2

Age distribution (Fig. 2) has shown no marked change, although a greater number of older patients come to operation now than formerly. The increased age of the patients may account in part for the increased percentage of lobectomies in the present compared to the earlier report. In the period 1948 to 1956, there were 93 lobectomies and 127 pneumonectomies (43 per cent lobectomies). In the period 1933 to 1948, there were 34 lobectomies, 87 pneumonectomies (28 per cent lobectomies).

Operative mortality for pulmonary resection appears to have stabilized at a reasonable level. Among 127 pneumonectomies in the years 1948 to 1956, there were 13 hospital deaths—a mortality rate of 10 per cent. In the same years, there were 93 lobectomies with 6 hospital deaths—a mortality rate of 6.4 per cent. It is interesting in view of the widely held clinical impression that right pneumonectomy is a more severe operation than left that, in this same period, there were 66 right pneumonectomies with 6 deaths (9 per cent) and 61 left pneumonectomies with 7 deaths (11 per cent). That right pneumonectomy was avoided in favor of lobectomy which carried an over-all mortality of 6.4 per cent is suggested by the fact there were 58 right-sided as opposed to 35 left-sided lobectomies in the same period.

SURVIVAL

The survival of patients undergoing resection is presented in the form of cumulative survival rates similar to life tables. The method has been described in detail by Hill[2] and by Puffer.[3] Table I is representative of the method. Here are presented the cumulative survival rates for all patients undergoing pneumonectomy in the years 1948 to 1956 followed to January, 1958. Date of operation is taken as zero time for a given individual. Mortality rates are calculated for each 6-month period thereafter by dividing [the number of individuals entering a given period and at risk during that period] by [the number of deaths occurring during that period]. If the mortality rate for a given period is subtracted from 100 per cent, a survival rate for the period results. If this, in turn, is multiplied by the cumulative survival rate for the previous period, a cumulative survival rate for the entire series at a given time period is established. The results can be effectively shown graphically (Fig. 3). The method permits the maximum use of a group of patients under study by correcting for patients who are lost to follow-up or for other reasons drop out of the study. In the present material, no patient was lost to follow-up except by virtue of the

TABLE I. CUMULATIVE SURVIVAL
1948-1956

TIME PERIOD ENDING (YEARS)	DEATHS	DROPPED FROM STUDY	PATIENTS ENTERING	PATIENTS AT RISK	PERIOD MORTALITY	PERIOD SURVIVAL	CUMULATIVE SURVIVAL
			Pneumonectomy				
½	43	0	127	127	34	66	66
1	17	0	84	84	20.2	79.8	53
1½	14	0	67	67	20.9	79.1	42
2	6	0	53	53	11.3	88.7	37
2½	5	1	47	46.5	10.8	89.2	33
3	6	1	41	40.5	14.8	85.2	28
3½	3	1	34	33.5	8.9	91.1	25
4	0	1	30	29.5	0	100	25
4½	0	2	29	28	0	100	25
5	1	1	27	26.5	3.8	96.2	24
			Lobectomy				
½	20	0	93	93	21.5	78.5	79
1	11	0	73	73	15.1	84.9	67
1½	6	0	62	62	9.7	90.3	60
2	4	0	56	56	7.1	92.9	56
2½	6	1	52	51.5	11.6	88.4	50
3	8	2	45	44	18.2	81.8	41
3½	2	2	35	34	5.9	94.1	39
4	3	0	31	31	9.7	90.3	35
4½	1	3	28	26.5	3.8	96.2	34
5	1	2	24	23	4.3	95.7	33

fact that operation was done an insufficient length of time prior to the time period under study Thus a patient operated upon 26 months before his last recorded follow up note would drop out of the study after the time period ending at 2 years and he would appear in the column marked "lost to the study"

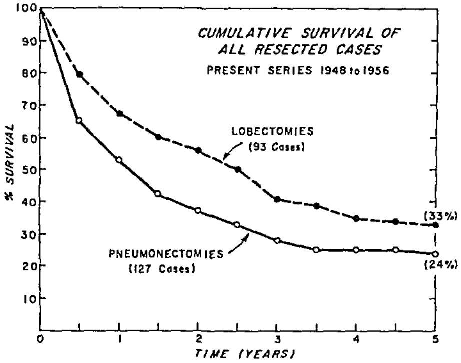

Fig 3

By convention, such an individual would be considered "at risk" during half the time period in which he was lost to follow up The number of "patients at risk" during a given period, therefore, is the number entering a given period minus one half the numbers of patients "lost" to the study during that period In order to permit comparison and consolidation the survival data of the previous report have been recalculated according to this method of Hill Table II presents the 10 year cumulative survival statistics for the entire series

TABLE II CUMULATIVE SURVIVAL
ALL RESECTIONS 1933 1956

TIME PERIOD ENDING (YEARS)	DEATHS	DROPPED FROM STUDY	PATIENTS ENTERING	PATIENTS AT RISK	PERIOD MORTALITY	PERIOD SURVIVAL	CUMULATIVE SURVIVAL
1	148	0	341	341	43	57	57
2	46	0	193	193	23.8	76.2	43
3	37	5	147	144.5	25.6	74.4	32
4	9	4	105	103	8.7	91.3	30
5	6	8	92	88	6.8	93.2	28
6	5	10	78	73	6.8	93.2	26
7	3	4	63	61	4.9	95.1	25
8	6	5	56	53.5	11.2	88.8	22
9	3	6	45	42	7.2	92.8	20
10	3	10	36	31	9.7	90.3	18

For the sake of clarity results have been presented graphically in Figs 4, 5, and 6 These show (1) the 5 year cumulative survival rate for the present series of resections compared with the original series considering only patients who survived operation and therefore had the opportun [illegible] Fig 4

(2) the 10-year cumulative survival rate for the total series—all cases undergoing resection in the years 1933 to 1956 (Fig. 5); (3) the 5-year cumulative survival rates for "survey" cases compared with all resections for the years 1948 to 1956 (present series) (Fig. 6).

In the present series there was a 24 per cent 5-year cumulative survival rate for 127 pneumonectomies and a 33 per cent 5-year cumulative survival rate for 93 lobectomies. Detrimental to the survival rate of the pneumonectomy group is the higher operative mortality rate (10 per cent for pneumonectomy, 6.4 per cent for lobectomy) plus the higher incidence of "positive" lymph nodes (88) among the pneumonectomy patients (69 per cent) as opposed to 33 in the lobectomy group (36 per cent). Whether the lobectomy group would have fared better had they had pneumonectomy is speculative.

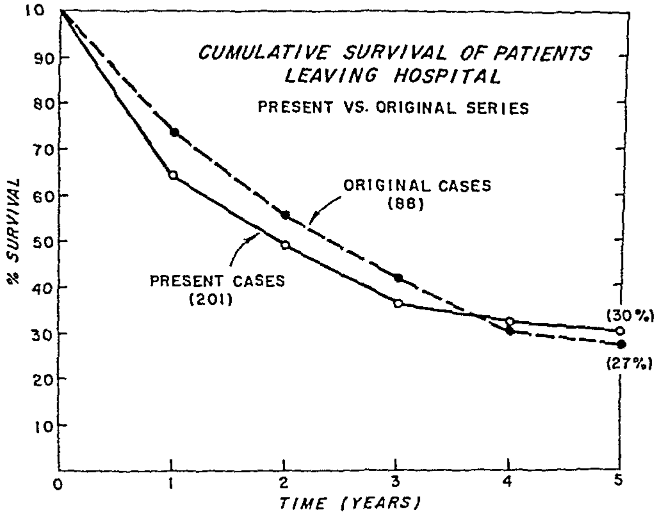

Fig. 4.

It is interesting to note that there has been no significant improvement in survival statistics in the present compared with the original series if the factor of operative mortality is excluded (see Fig. 4). It is reasonable to do this since many of the original series were operated upon during the developmental phase of surgery for pulmonary carcinoma. This should not be interpreted to imply that efforts to increase the extent of operation are futile.

Cumulative 10-year survival rates are shown in Fig. 5. There is an appreciable mortality in the 5- to 10-year period after operation. We cannot say with certainty how much of this mortality can be ascribed to age and intercurrent disease since perforce the majority of our death reports rely on clinical diagnosis and the tables are not comparable to ordinary life tables. However, many of the late deaths, probably more than half, were the result of recurrent or metastatic cancer. There is, as might be predicted, a flattening of the survival curve after 5 years and it is reasonable to conclude that 5-year survival is a significant measure of therapy in cancer of the lung.

The survival rate for "survey" cases is interesting in view of the optimistic hope now prevalent that earlier detection of cases will result in a greater percentage of survivals The definition of "survey" cases is admittedly an approximate one The 5-year cumulative survival rate for 38 "survey" cases operated upon in the years 1948 to 1956 was 42 per cent compared with 28 per cent for all resections carried out during the same period (Fig 6).

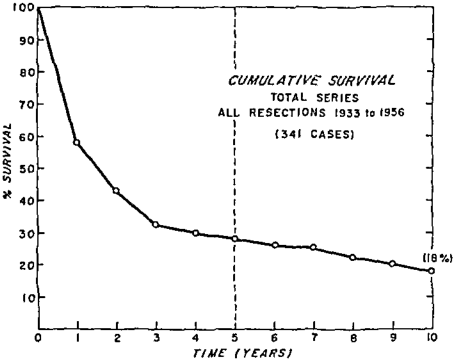

Fig 5

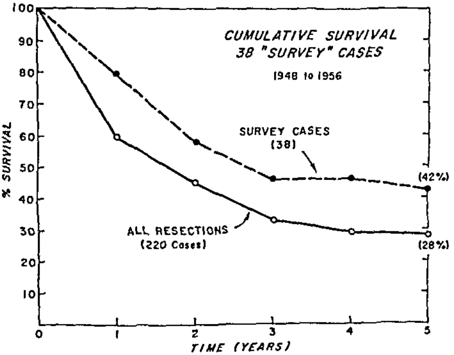

Fig 6

EFFECT OF POSITIVE NODES

One of the most difficult aspects of the cancer problem, whether it be of the lung or of any organ, is to measure accurately the importance of lymph node metastasis There are an enormous number of variables. We have therefore, been reluctant to dwell on this aspect of the [illegible]

Our material does not permit an accurate statement of number of nodes involved and whether or not these could be defined as intrapulmonary, regional, mediastinal, and other conventional designations. However, as a clinical measure, if we accept the notation of the pathologist who examined the specimen in a careful but "routine" way, we discover the following results. Of 56 patients undergoing pneumonectomy in the period 1948 to 1953 in whom at least one positive node was found, 9 were alive at 5 years (16 per cent); of 28 having pneumonectomies with "negative" nodes for the same period, produced 13 5-year survivals (46 per cent). Of 15 patients with positive nodes who had lobectomy in the same period, 3 (20 per cent) survived 5 years; of 43 patients with negative nodes and lobectomy 15 (35 per cent) survived 5 years.

SUMMARY

The experience with surgical resection of primary carcinoma of the lung at the Massachusetts General Hospital from 1950 to 1957 has been reviewed and added to a similar report from that hospital which covered the years 1930 to 1950. Complete follow-up data are available in all resected cases (341). These data show:

1. In the recent 7-year period, a greater percentage of patients with proved carcinoma of the lung have come to operation than in the earlier series (55 per cent compared with 43 per cent). The resectability rate has also increased (35 per cent of proved cases compared with 25 per cent).
2. The 5-year cumulative survival rate for all patients undergoing resection for cancer of the lung remains approximately 28 per cent.
3. The 10-year cumulative survival rate for such patients is 18 per cent.

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(For Discussion, see page 324)

SHOULD WE INSIST ON "RADICAL PNEUMONECTOMY" AS A ROUTINE PROCEDURE IN THE TREATMENT OF CARCINOMA OF THE LUNG?

Julian Johnson, M D , D Sc (Med), Charles K Kirby, M D , and William S Blakemore, M D , (by invitation), Philadelphia, Pa

AT A MEETING of the American Association for Thoracic Surgery in Denver in 1950, Allison, in discussing the paper of Churchill[1] and associates on cancer of the lung, proposed the term "radical pneumonectomy" to describe the removal of all possible mediastinal areolar tissue, containing the lymphatics in continuity with the lung, thereby employing the principle previously utilized in operations for cancer in other parts of the body

At about that time, Watson at the Memorial Hospital in New York became interested in the concept of radical pneumonectomy and subsequently published several papers on the subject[2, 3] As described by Watson, the dissection starts at the apex of the mediastinum and all areolar tissue and lymph nodes are reflected downward as the trachea, esophagus, and other important structures, as well as the contralateral bronchus are partially "skeletonized " The pericardium is resected with the lung and mediastinal tissues after the pulmonary vessels have been divided intrapericardially

A few years ago the American Cancer Society gave wide circulation to the excellent motion picture made by Watson and his associates on the subject of radical pneumonectomy This film implied that anyone doing less than a radical pneumonectomy for cancer of the lung might not be doing everything possible to cure his patients We had been removing lymph nodes in the mediastinum immediately adjacent to the hilum, going over as far as the bifurcation of the trachea, but resected the more distant nodes only when there seemed to be involvement of those nodes and, therefore, found ourselves on the defensive regarding the surgical treatment of pulmonary cancer after viewing this film When we asked our surgical friends around the country whether they performed radical pneumonectomies, they seemed hesitant to admit that they did not and if they did admit it it seemed to us that they did so somewhat sheepishly

The reason for feeling on the *defensive concerning radical* pneumonectomy is that it seems so reasonable, following the same concepts which led to the adoption of radical mastectomy for cancer of the breast and radical right

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colectomy for cancer of the cecum. If it is true that cancer spreads chiefly through lymphatic channels, it would seem that there could hardly be any disagreement on this subject. It is true that the lymphatic drainage tracts from the lung cross the mediastinum, making it difficult to remove all of the offending lymphatic channels even by radical pneumonectomy, but then the lymphatic channels from the breast often traverse the chest wall to enter the mediastinum, thus not being accessible in the ordinary radical mastectomy. The question naturally arises, will a super-radical pneumonectomy be proposed in which both pleural cavities are opened and the lymph node bearing tissue removed from both sides of the mediastinum, and the dissection perhaps carried up to and including the supraclavicular lymph node bearing areolar tissue? This super-radical operation has already been proposed for mammary cancer and has been carried out by some surgeons. It is obvious that it is up to the advocates of radical pneumonectomy for cancer of the lung to demonstrate that it produces better results than the standard type resection.

It should be pointed out that even the advocates of radical pneumonectomy do not use it routinely. Watson[2, 3] has limited its use to the patients who are considered good surgical risks and, indeed, only 55 per cent of his resections were classified as radical pneumonectomy.

We shall not belabor the point that radical pneumonectomy may carry a higher mortality than the standard procedures because it is difficult to compare mortality figures in various series done under various circumstances. However, it seems likely that, in general, the more radical the procedure for any condition, the higher the risk. When Allison discussed this point in 1950,[1] he mentioned that his mortality had been very high in his early experience with radical pneumonectomy, although in the year of 1949 he had been able to hold it down to less than 5 per cent. In his total series, however, the mortality was 23 per cent. Watson,[3] on the other hand, had a mortality of only 5.5 per cent in 74 radical pneumonectomies done from 1949 to 1951, whereas the mortality jumped to 25 per cent in 51 radical pneumonectomies done from 1952 to 1955. This seems high when one considers that only the good risk patients were subjected to radical pneumonectomy during that period. It also illustrates that mortality statistics may be unreliable in short series, since the difference between the 5.5 per cent and 25 per cent in consecutive 3-year periods is so striking. The total mortality for the 6-year period was 13.6 per cent. There can be no doubt that radical pneumonectomy has been carried out in the hands of a good many surgeons with a low mortality rate, at least for a period of time, but it seems probable that any thoracic surgeon who may be tempted to embark on such a program should give some consideration to the probability of increasing his mortality rate at least temporarily.

The decision as to whether radical pneumonectomy should be insisted upon, at least in good risk patients, must depend upon whether better results have been obtained than by the standard techniques. No one can deny that there is a certain attractiveness to the thesis that results might be improved by getting the last lymph node involved by lymphatic spread. It has now been

8 years since Allison proposed the term "radical pneumonectomy." As far as we know, Watson has published the largest series in which 5-year survival data are given. In his article published in 1956,[3] survival data were given on 116 patients operated upon during the years 1949 to 1951 (Table I). Seventy-four patients in that group were subjected to radical pneumonectomy with an operative mortality of 5.5 per cent and a 5-year survival of 27 per cent.

TABLE I. WATSON—5-YEAR SURVIVAL IN LUNG CANCER

RESECTION	NO.	% OPERATIVE MORTALITY	% 5-YEAR SURVIVAL
Radical pneumonectomy	74	5.5	27
Simple pneumonectomy	26	7.7	23
Lobectomy	16	18.7	25
Totals	116	7.7	26

Twenty-six patients in that same period had a standard pneumonectomy with a 5-year survival of 23 per cent, and 16 had a lobectomy with a 5-year survival of 25 per cent. In the total series, the 5-year survival was 26 per cent. Watson *was encouraged to continue the use of radical pneumonectomy on the basis* of the differential 5-year survival of 27 per cent for radical pneumonectomy and 23 per cent for standard pneumonectomy. When one considers, however, that it was the good risk patients who were subjected to radical pneumonectomy and that age is certainly one of the factors involved in the risk, it would not seem at all improbable that a higher percentage of the aged were subjected to simple pneumonectomy and that this might very well account for the lower 5-year survival rate in that group. It might also be suggested that the second 3-year period may not give as good a 5-year survival since the mortality for radical pneumonectomy in that period jumped from 5.5 to 25 per cent.

Gibbon and his associates[4, 5] have advocated an aggressive approach in resection for carcinoma of the lung. In their report covering 145 resections,[4] the vessels were divided intrapericardially in about 50 per cent. The report implies, however, that the radical operation was used for the extensive lesions rather than the early ones. They contended that lobectomy was justified only when the patient's condition would not permit a pneumonectomy.[5] The 5-year survival in their series of 145 resections was 21 per cent.

It seemed to us that it would be worth while to review our 5-year survival data since we have performed the standard type resection exclusively in our series. It is true that we have sometimes done more radical operations for carcinoma of the lung, ligating the vessels inside the pericardial sac and resecting large masses of nodes involved by tumor, but we have not "skeletonized" the trachea, the esophagus, and the great vessels in the mediastinum in good risk patients with early carcinoma. Our radical procedures have been confined to those patients who had tumors outside of the lung, making it necessary to carry out a more extensive resection in order to get around the palpable tumor. Thus, none of our patients can be said to have had a radical pneumonectomy in the sense that it was proposed by Allison.

The experience with carcinoma of the lung at the Hospital of the University of Pennsylvania from Jan. 1, 1939, to Jan. 1, 1958, was with 764 patients. Fifty-one per cent were explored and 33 per cent were subjected to resection. The operative mortality was 8.6 per cent. Not all of these patients had histologic proof of carcinoma of the lung. Some, who were not subjected to operation, had a clinical diagnosis only and many of them were never seen by our surgical group. However, it was the clinical impression that these patients did have carcinoma of the lung and we present these data regarding the entire series in an effort to show the true ravages of the disease rather than confining ourselves only to those cases which were seen by us personally and histologically proved. Because of this, the figure of 33 per cent of the patients of the entire series being subjected to resection may seem a bit low as compared with other series, but 65 per cent of those explored were subjected to resection and this is in accord with other reported series. In this report we have confined our attentions to the patients seen more than 5 years ago. In the period from Jan. 1, 1939, to April 1, 1953, a total of 344 patients who clinically were judged to have cancer of the lung were seen at the Hospital of the University of Pennsylvania (Table II). Of these, 192 (56 per cent) were explored, and 116 (34 per cent) were subjected to pulmonary resection. There were 9 deaths, giving an operative mortality of 7.7 per cent. Of this group of 116 patients, 31 lived for 5 years or more, giving a 5-year survival rate of 26.7 per cent of those subjected to resection or 9 per cent of all patients judged clinically to have carcinoma of the lung. In the group subjected to resection 99 had pneumonectomy with 26 per cent 5-year survival, and 17 had less than a pneumonectomy with 35 per cent 5-year survival. It will be seen that our 5-year survival rate of 26.7 per cent is comparable to that of Watson's 27 per cent and is essentially the same as Gibbon's 21 per cent if one takes into consideration the difference in operative mortality. Using the published 5-year data from the six clinics[1, 2, 4, 6, 7] shown in Table III, it would appear that the 5-year survival rate tends to show an inverse relationship to the operative mortality.

TABLE II. CARCINOMA OF LUNG JANUARY 1, 1939—APRIL 1, 1953

	NO. OF PATIENTS	%	5-YEAR SURVIVAL	
			NO.	%
Clinical diagnosis	344			
Explored	192	56.		
Resected	116	34.	31	26.7
Operative mortality	9	7.7		
Pneumonectomy (standard)	99	7.	26	26.4
Less than pneumonectomy	17	13.	6	35.

It is admittedly rather early to be judging the results of radical pneumonectomy since the number of patients operated upon by that technique more than 5 years ago is still comparatively small. At the present time, however, and until further data are available, it cannot be said that radical pneumonectomy is a superior operation to the standard type resection from the standpoint of 5-year survival.

TABLE III 5 YEAR SURVIVAL—CARCINOMA OF LUNG

SENIOR AUTHOR AND YEAR		NUMBER RESECTED	% OPERATIVE MORTALITY	% RESECTED PATIENT 5 YEAR SURVIVAL	% TOTAL PATIENT 5 YEAR SURVIVAL
Churchill	1950	69	19.9	14.5	
Overholt	1956	234	15	22	7.6
Ochsner	1956		19.2	15	5.5
Watson	1956				
Radical pneumonectomy		74	5.5	27	
Less than radical pneumonectomy		42	11	23.8	
Gibbon	1956	145	23	21	8.4
Johnson	1958	116	7.7	26.7	9

It has only been within the last few years that we have had a clue which may help to explain why radical pneumonectomy, at least to date, has not been shown to be superior to the standard type resection for cancer of the lung. We believe the explanation may lie in recent evidence regarding the spread of pulmonary cancer through the blood stream as well as through the lymphatic channels. Dr. Fred Collier, until recently one of our pathologists, became interested in this problem.[8, 9] By means of special stains he studied the surgical specimen for evidence of blood vessel invasion. He was interested in knowing whether the presence or absence of blood vessel invasion in the surgical specimen could be correlated with the survival. In this study he found demonstrable blood vessel invasion in 71 per cent of the surgical specimens. Further studies[10] indicated that blood vessel invasion was of far greater prognostic significance than the presence or absence of lymph node invasion. For many years surgeons[11] have been aware that there is considerable difference in the cellular type of tumors and that some tumors spread rapidly and others spread slowly. It seems to us that Collier and others who have studied this problem may have disclosed a crucial factor in the widespread dissemination of these tumors. As has previously been reported,[10] it was found that undifferentiated carcinomas all showed blood vessel invasion, whereas only 63 per cent of the epidermoid carcinomas, 45 per cent of the bronchiolar carcinomas and 12 per cent of the carcinoid adenomas showed blood vessel invasion. The presence or absence of blood vessel invasion has a profound influence upon 5 year survival. In our present series (Table IV) of 71 patients with blood vessel invasion, only 4 (6 per cent) survived 5 years, whereas of 36 patients without blood vessel invasion 27 (75 per cent) survived 5 years. This is of much greater significance than the presence or absence of lymph node invasion. For example, of 53 patients with lymph node invasion, only 8 (15 per cent) survived 5 years, whereas of 54 patients without lymph node invasion, 23 (43 per cent) survived 5 years. On the other hand, if the patient had blood vessel invasion, the presence or absence of lymph node invasion had no significance. In the absence of blood vessel invasion the presence of lymph node invasion was of some significance since of 10 such patients only 6 (60 per cent) survived 5 years. The best results were in the group of 26 patients with neither blood vessel nor lymph node invasion in which 21 (81 per cent) survived 5

TABLE IV. CARCINOMA OF LUNG—5-YEAR SURVIVAL OF 107 PATIENTS SURVIVING RESECTION

	BLOOD VESSEL INVASION	LYMPH NODE INVASION	RESECTED	ALIVE 5 YEARS	PER CENT
1.	+		71	4	6
2.	-		36	27	75
3.		+	53	8	15
4.		-	54	23	43
5.	+	-	28	2	7
6.	+	+	24	2	8
7.	-	+	10	6	60
8.	-	-	26	21	81

If these studies of Collier and his associates are confirmed by other groups, perhaps we should revise our thinking regarding carcinoma of the lung. Formerly, spread through lymphatic channels appeared to be the most reliable prognostic criteria and it seemed reasonable to extend the scope of the operation in the hope of getting around all lymphatic spread. Now it seems likely that the spread through the blood stream is of greater significance but that extension of the scope of the resection cannot possibly influence this factor. As far as we know, these observations on the relationship of blood vessel invasion to 5-year survival have not yet been confirmed in other clinics. It is of some interest to note, however, that whereas our pathologists found 71 per cent of the surgical specimens to show blood vessel invasion, Moore and his associates,[12] who have used a technique for demonstrating cancer cells in the blood stream, have found cancer cells in approximately 75 per cent of the patients with cancer of the lung.

At the present time there are no data available to indicate when blood vessel invasion occurs in a cancer of the lung. We can only say that we have seen it present in small tumors and absent in large ones. Our data would suggest that if it is present in a small tumor, even a radical pneumonectomy is not likely to save the patient from widespread dissemination of the lesion. On the other hand, the fact that it may be absent in a large tumor has spurred us on to make an increased effort to get around such a tumor when it is technically possible to do so. It would appear obvious that if there is not blood vessel invasion and if the tumor has spread through the lymphatics, a radical pneumonectomy might offer a better chance of getting around "that last lymph node" which may be involved. Our fear has been that the occasional gain made on this basis might be more than offset by an increase in the mortality.

SUMMARY

1. In an experience with 764 patients with carcinoma of the lung at the Hospital of the University of Pennsylvania, 344 were seen more than 5 years ago. Of this group, 192 (56 per cent) were explored and 116 (34 per cent) were subjected to pulmonary resection. The operative mortality was 7.7 per cent. Thirty-one or 26.7 per cent of those subjected to resection, or 9 per cent of the total number of patients, survived 5 years or more. "Radical" pneumonectomy was not employed in this series.

2 The 5 year survival so far reported following "radical" pneumonectomy is not significantly higher than we have obtained with the standard type resection

3 It is suggested that until it can be shown that "radical" pneumonectomy produces superior results, the thoracic surgeon is not obligated to perform the radical operation However, we do not wish to discourage the resection of all grossly involved tumor tissue and feel that the surgeon should make a real effort to get around the locally invasive tumor whenever possible

4 Studies to date indicate that blood vessel invasion as found in the surgical specimen is of greater prognostic significance than lymph node invasion Whereas there was only a 6 per cent 5 year survival in those patients showing blood vessel invasion in their tumor, there was a 75 per cent 5 year survival when blood vessel invasion was not present This may in part account for the fact that radical pneumonectomy to date has not produced the great improvement in the 5 year survival rate which was anticipated

We wish to express our appreciation to Dr Samuel Askowitz and Miss Mary Jane English for their assistance in compiling the statistical data

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(For Discussion, see page 324)

RESULTS IN THE TREATMENT OF BRONCHOGENIC CARCINOMA

An Analysis of 1,008 Cases

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Thomas B. Ferguson, M.D. (by invitation), and
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ONE thousand and eight patients with primary carcinoma of the lung were seen by the senior author and his associates at the Barnes Hospital between Jan. 1, 1948, and Dec. 31, 1955. Appropriate data were obtained from the total case record of each of the 1,008 patients for this analysis. The diagnosis was verified in 100 per cent of the cases by microscopic section, the material being obtained by bronchoscopic biopsy, sputum cytology, biopsy of metastatic implants, needle biopsy, frozen section biopsy at the time of thoracotomy, and examination of the resected specimens.

The date of follow-up was July 1, 1957. The minimum follow-up period of this group was therefore 1½ years and the maximum 9½ years. No autopsy cases not seen and treated are included. A larger experience dating from the first pneumonectomy for carcinoma by Graham in 1933 to 1948 is not included. This earlier group for various reasons does not lend itself to accurate statistical analysis.

TABLE I. DISTRIBUTION OF LUNG CANCER BY AGE

AGE	NUMBER	PER CENT
20-29	2	
30-39	22	2
40-49	164	17
50-59	375	37
60-69	361	36
70-79	80	8
80-89	4	
Totals	1,008	100

SEX AND AGE

The ratio of men to women did not differ significantly from other reported series.[2, 4, 7] There were approximately 8 times as many men (88.4 per

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cent) as women (11.6 per cent). Age at the time of treatment ranged from 24 years to 85 years. The highest incidence was encountered in the fifth and sixth decades (Table I).

PATHOLOGY

While minor differences exist among surgical pathologists in the description of various types of lung cancer, most agree on a simple classification. The Surgical Pathology Division at the Barnes Hospital recognizes the following classification:

A. Epidermoid carcinoma
B. Undifferentiated carcinoma
C. Adenocarcinoma
D. Bronchiolar (alveolar cell) carcinoma
E. Small (oat) cell carcinoma.

All cases of bronchial adenomata have been excluded from this series.

CELL TYPE

The histologic nature of the tumors seen in this series proved very similar from the point of view of incidence to those reported from other centers.[3] The majority proved to be epidermoid (57 per cent). Undifferentiated carcinoma made up 28.5 per cent of the group, and adenocarcinoma 10 per cent (Table II).

TABLE II. HISTOLOGIC DIAGNOSIS

TYPE	NUMBER	PER CENT
Epidermoid	572	57.0
Undifferentiated	287	28.5
Adenocarcinoma	107	10.5
Bronchiolar	13	1.0
Small (oat) cell	15	1.5
Mixed epidermoid and adenocarcinoma	14	1.5
Totals	1,008	100.0

SITE

The right lung was the site of the cancer in 580 patients, and the left in 428. The tumor arose in the upper lobes in 485 (48 per cent) patients. The right upper lobe was the most frequent site (25 per cent). The distribution is shown in Table III.

TABLE III. SITE OF THE LUNG CANCER

BRONCHUS	NUMBER	PER CENT
Right main	85	8.5
Right upper	252	25.0
Right middle	39	4.0
Intermedius	49	5.0
Right lower	155	15.0
Left main	86	8.5
Left upper	233	23.0
Left lower	109	11.0
Totals	1,008	100.0

SELECTION OF CASES

In the 1,008 patients, 390 or 38.6 per cent were not considered suitable for exploration (Fig. 1). In each of these cases the diagnosis was verified by appropriate biopsy material. The vast majority were inoperable because of generalized spread of tumor, including diffuse cerebral or bony metastases, bilateral pulmonary involvement, carinal, tracheal or chest wall extension. The number considered inoperable because of pulmonary insufficiency was small because of our policy of advising exploration on all so-called borderline cases as judged by function studies and clinical evaluation. Likewise very few patients were turned down because of co-existent cardiac or renal disease. In our experience, intractable heart failure is the only cardiorenal condition in which surgery almost invariably leads to serious difficulty. Age was not a deterrent. In only 2 patients, both in the 80's, was surgery not advised because of infirmity.

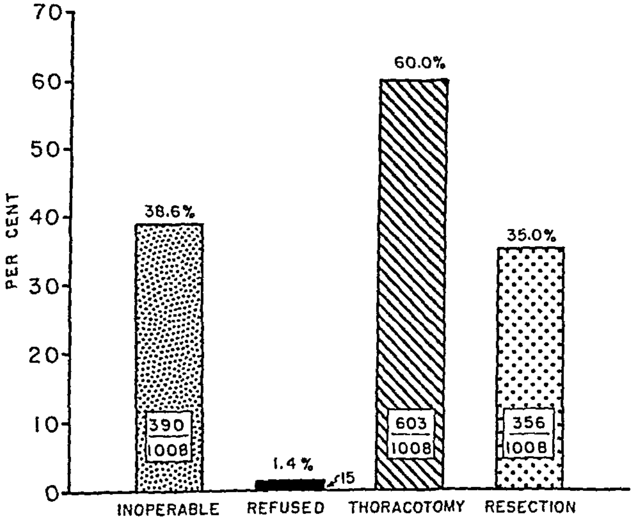

Fig. 1.—*Management of 1,008 cases of bronchogenic carcinoma.*

Our policy concerning exploration in the special instances of pulmonary cancer has always favored the side of surgical intervention whenever possible. This applies to cases of phrenic or recurrent laryngeal nerve involvement, chest wall involvement without extensive bony destruction, and to certain cases with positive scalene lymph node biopsy or positive pleural fluid. Surgery in many of these instances is obviously palliative. The results of such procedures defy statistical analysis, since the patient may not live a day longer than the natural course of the disease would allow, but if the patient is done no harm by operation and the quality of his remaining existence is improved, this certainly is as great a surgical dividend as prolongation of life. Surgeons must remember that life for the cancer patient is a matter of quality not quantity. For this reason surgeons treating pulmonary cancer must not let themselves be hampered by hard and fast rules of operability and inoperability. In this regard, experience and judgement count far more than the rule book. For example, those who contend that a positive scalene node biopsy is a contraindication to surgery will be doing a number of patients a grave injustice in terms of ultimate comfort.

RESECTABILITY RATES

In addition to the 38.6 per cent considered clinically inoperable, 15 patients (1.4 per cent) refused surgery (Fig. 1). The remaining 603 patients (60 per cent) had exploratory thoracotomy, and resection was done in 356 of them. Thus, the resection rate for the entire 1,008 cases was 35 per cent. In the other 247 explorations, the tumor was found to be nonresectable, the majority because of invasion of hilar blood vessels.

Pneumonectomy was the preferred operative procedure for all cell types except bronchiolar carcinoma, for which lobectomy was favored. Of the 356 resectable cases, 280 or 79.3 per cent, had pneumonectomies, 74 (20.2 per cent) had lobectomies, and 2 (0.5 per cent) had segmental resection (Fig. 2). Our figures show that in spite of a preference for pneumonectomy, the percentage of lobectomy cases has been steadily increasing. Whereas in 1948 lobectomy comprised only 3.3 per cent of the total resections, in 1955 the percentage had increased to 29.5 per cent. We attribute this rise to the extended use of lobectomy in palliation and in older patients with borderline respiratory reserve, plus its use in selected cases of small peripheral solitary tumors.[8] This latter group has not been large in our series. In the 2 cases of segmental resection 1 was a mistaken frozen section diagnosis in which re-operation was not advised, and the other was a palliative resection for a peripheral tumor with involvement of the chest wall and pain in a poor risk patient.

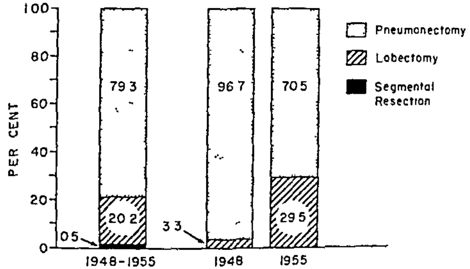

Fig 2.—Type of resection.

OPERATIVE MORTALITY

There were 69 deaths (11.0 per cent) within the first 2 months following surgical exploration (Table IV). Approximately one half of the deaths were due to cardiovascular complications. The routine use of prophylactic preoperative digitalization during the past few years has significantly reduced the number of cardiovascular disturbances which endanger [illegible] older age patient. In the group in which the tumors were found nonresectable at operation, the mortality was 8.8 per cent. Deaths in cases of pneumonectomy totaled 13.0 per cent. and in the lobectomy cases 12.0 per cent.

TABLE IV. OPERATIVE MORTALITY

OPERATION	NUMBER OF CASES	NUMBER OF DEATHS	PER CENT
Exploration	247	22	8.8
Pneumonectomy	280	37	13.0
Lobectomy	74	9	12.0
Segmental resection	2	1	50.0
Totals	603	69	11.0

SURVIVAL RATES

In analyzing these results, those patients who were never heard from, once they left the hospital, are not included (4.4 per cent). In cases where the patient was heard from or seen months or years later and then no further follow-up obtained, it was assumed that the day the patient was last seen or heard from was the expiration date, and that death was due to the cancer.

Of 1,008 cases of primary carcinoma of the lung in this series, 482 patients were treated between January, 1948, and July, 1952. Of these, follow-up was obtained in 461 (95.6 per cent), which represents the total number of cases available for survival analysis 5 to 9½ years after diagnosis (Fig. 3). Resections were performed in 182 of these 461 cases, a resectability rate of 39.5 per cent. The 5-year survivors in these 182 cases numbered 40 patients, a survival rate of 22 per cent. Seventy patients (38.4 per cent) lived more than 2 years following operation. The critical period of survival in this series was the first 30 months after resection. Of the patients who survived at least 30 months, 75 per cent lived on to become 5-year survivors.

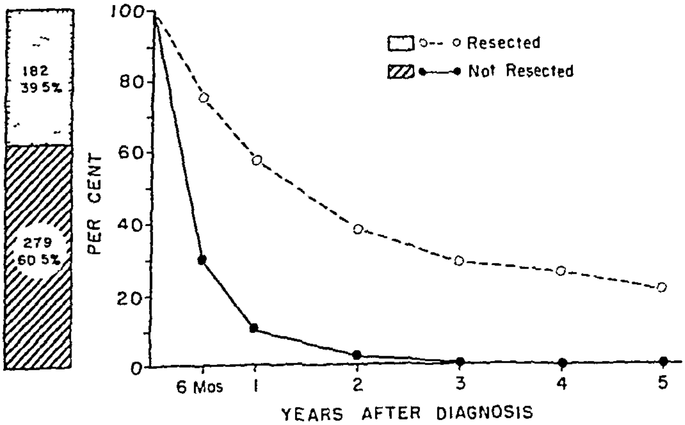

Fig. 3.—Survival—461 cases. January, 1948—July, 1952.

There were no 5-year survivors in the remaining 279 inoperable or nonresectable patients, even though almost all of them were treated with x-ray therapy or chemotherapy or both. Seventy per cent of these patients were dead within 6 months, and only 4 patients, or 1.4 per cent, were alive after

2 years, which again emphasizes the necessity of recommending surgery if at all possible in the treatment of this disease. Thus, 40 persons out of the original group lived 5 or more years, an over-all survival rate of 8.7 per cent.

An analysis of the resected specimens on these 40 long-term survivors showed, as would be expected, that epidermoid carcinoma was the predominant cell type, occurring in 31 of the 40 cases (Fig. 4). There were 5 cases of undifferentiated carcinoma, representing 12.5 per cent of the total number. This gratifying finding increases our optimism about this type of cancer of the lung and certainly leads us to take exception with those who believe that patients with known undifferentiated carcinoma should not be treated surgically. There were 2 cases each of bronchiolar cell tumor and adenocarcinoma.

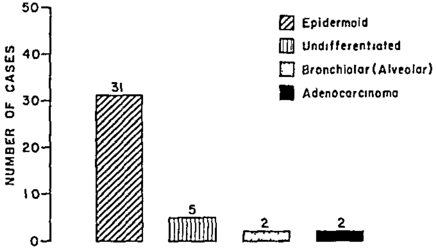

Fig. 4.—Cell type—40 cases with 5-year survival.

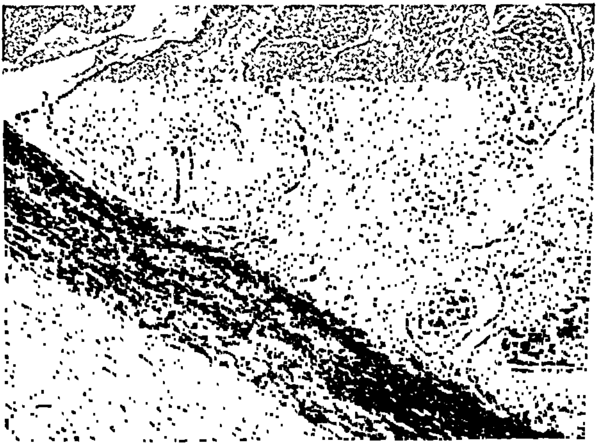

Fig. 5.—Photomicrograph showing invasion of the main pulmonary artery by epidermoid carcinoma. The vessel wall with stained elastic fibers is at the lower left. This patient is alive and well more than 5 years following resection (Verhoeff-van Gieson, ×125)

The 40 specimens were further analyzed for frequency of [illegible] blood vessel invasion (Table V). A totally unexpected fi the 40 cases, or 45 per cent, had involvement of lymph nodes by tumor. The number of involved nodes in these 18 cases ranged from 1 to 7, with the average being 2½ nodes per case. Three of the 40 cases, 8 per cent, had obvious blood vessel invasion on routine hematoxylin and eosin stains, and 2 of these 3 cases also had lymph node involvement. This high proportion of survivors with tumor extension to lymph nodes is unusual, since most survival statistics show the great preponderance of patients living 5 years have negative nodes.[2, 5] It has recently been shown that blood vessel invasion may be a more important factor in determining prognosis than lymph node invasion[1] (Fig. 5).

TABLE V. EXTENSION OF TUMOR—40 CASES WITH 5-YEAR SURVIVAL

Lymph node involvement	18 cases—45%
Range per case	1 to 7 nodes
Average per case	2.5 nodes
Blood vessel invasion	*3 cases— 8%*

From July, 1952, to December, 1955, a diagnosis of pulmonary cancer has been made in 522 cases, and 496 (95 per cent) have been followed from 1½ to 5 years (Fig. 6). The ultimate long-term survival figures are of course not complete, but it is interesting to compare trends in this group of cases with the 5 to 9½ year group. The number of patients we are seeing with cancer of the lung is increasing each year. In the earlier period—spanning 4½ years—461 cases were diagnosed; whereas in the more recent period covering only 3½ years, 496 cases were seen. There is no indication that lesions are being seen at an earlier stage, for the resection rate is actually lower in the 1952-1955 group, 32.3 per cent, compared with 39.5 per cent for 1948-1952. There is likewise no indication that any significant refinement or extension of surgical techniques has been achieved, since comparison of percentage survival of resected cases in the 2 groups is essentially the same. Of the 160 patients resected from July, 1952, on, 115 have been followed a minimum of 30 months and, of these, 20 per cent are alive. In the 1948-1952 group the comparable figure for 30-month survival was 25 per cent.

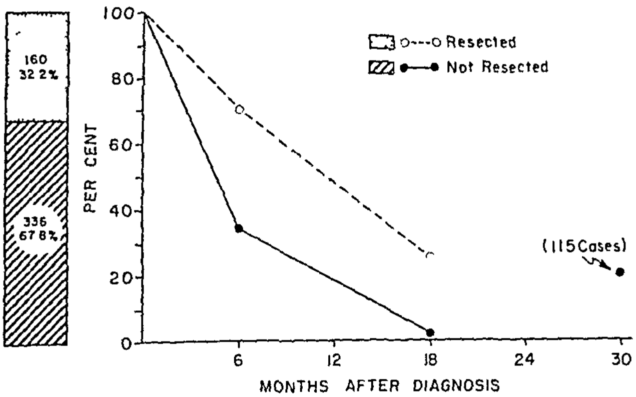

Fig. 6.—Survival—496 cases. July, 1952—December, 1955.

DISCUSSION

This study once again re-affirms the discouraging uniformity of results that are being obtained throughout the country in the treatment of pulmonary cancer. Table VI shows clearly the fundamental problem: Only one third of all the patients who develop carcinoma of the lung are surgically resectable and thus eligible for long-term survival. At Barnes Hospital there has been no change in the percentage of resectable cases over the past 9½ years. Improvements have come in many areas in recent times. The mortality rates for surgery are quite low, the poor risk patients are being operated upon more successfully, and so forth. *But until a larger number of the total case group can be* seen at a time when the lesion can be removed, it is unlikely that the 5-year survivor group will ever get over 10 per cent. We do not feel on the other hand that there is cause for too much pessimism or that talk of fate or biologic predeterminism should cloud the issue.[6] The high incidence of 5-year survival we obtained in cases of undifferentiated carcinoma, and in cases with gross lymph node and blood vessel invasion, has reinforced our feeling that the most important step in curing cancer is still the surgical removal of all tumor-containing tissue, and that all patients should be considered for resection if there is reasonable belief that this can be done. It is certainly true that there are some cases of pulmonary cancer where growth is so rapid and invasive that the patient is going to die no matter when the diagnosis is made. It is also true that in other cases growth is so slow that the diagnosis can be missed by several physicians and still a good result will ensue. But the vast majority of cancers of the lung we have seen progress in an orderly fashion, and without undue rapidity—from curable to the incurable stage. This being the case it should be possible with all the diagnostic aids and knowledge at hand to discover them in the phase of growth when resection can be done on the majority.

TABLE VI

AUTHOR	NO. CASES	PER CENT EXPLORED	PER CENT RESECTED	PER CENT 5-YEAR SURVIVALS
Burford	1,008	60	35	9
Gibbon	532	71	39	9
Kirklin	767	48	24	8
Ochsner	1,170	52	33	8
Overholt	733	62	37	8

SUMMARY

1. One thousand and eight histologically confirmed cases of bronchogenic carcinoma have been seen between Jan. 1, 1948, and Dec. 31, 1955.

2. The distribution as to sex, age, cell type, and site of origin did not differ significantly from other reported series.

3. Surgical exploration was carried out in 60 per cent of cases. Resection was possible in 35 per cent. Pneumonectomy comprised 80 per cent of the resections, lobectomy 20 per cent. The percentage of lobectomy cases increased from 3 per cent in 1948 to 30 per cent in 1955.

4. The over-all operative mortality was 11 per cent.

5. The 5-year survival rate for all patients followed an adequate length of time was 9 per cent. In the select group in whom surgical resection was possible, the 5-year survival rate was 22 per cent.

6. Study of the resected specimens from the 5-year survivors revealed epidermoid carcinoma to be the most prevalent cell type (77.5 per cent), but a surprisingly high number of undifferentiated tumors (12.5 per cent) were present. Almost half (45 per cent) of the specimens showed lymph node involvement, and 8 per cent had blood vessel invasion.

7. Surgical resection could be done in only 1 of each 3 diagnosed cases. This ratio remained unchanged throughout the 8-year span of this series. Significant increase in 5-year survivals will be possible only through an increase in the percentage of resections performed.

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DISCUSSION

(PAPERS BY CHURCHILL [PAGE 301], JOHNSON [PAGE 309], AND BURFORD [PAGE 316] AND THEIR ASSOCIATES)

DR. RICHARD H. MEADE, Grand Rapids, Mich.—We have heard three excellent papers on a very important subject. I was fortunate in being present at the meeting in 1933 when Dr. Graham reported his case. It is rather interesting that he was not on the program and, after some of the papers had been read, he rose and said, "Gentlemen, I think you will be interested in something I did last week." He then told us about this case. I think we should remember that the longest surviving patient with carcinoma of the lung, operated upon by Dr. Graham 25 years ago, had the most conservative type of pneumonectomy possible. There was no attempt to remove adjacent glands, and some lung tissue was left around the stump.

It occurs to me that the best way to study this problem is not shown in the series of cases presented today but rather from autopsies of patients who have had successful resections, to see what happened to them. Through the co-operation of Sir Clement Price Thomas in London, we have been able to study 73 cases; 50 of these were simple pneumonectomies and 23 were lobectomies. The average length of life at autopsy was 20 months; this interval varied from 3 months up to 96 months, the longest being 8 years before death.

There was no recurrence of cancer in 32 per cent at the time of autopsy. There was recurrence in ipsilateral glands in 28 per cent and in contralateral glands in 4 per cent. There was no recurrence in the pulmonary vessel stump in any case, and three recurrences in the pericardium.

In the 23 lobectomies there was no recurrence in 26 per cent; there was recurrence in the ipsilateral glands in 21 per cent, and no recurrence in the pericardium.

It is my hope that during the course of the next year I may have the co-operation of this Association so that a representative series may be studied. I believe this is a very interesting way to approach the problem, to see the end results of pulmonary resection.

DR. GABRIEL P. SELEY, New York, N. Y.—I would like to discuss the paper of Dr. Johnson. For a number of years at the Mt. Sinai Hospital in New York, Dr. Otani has studied all specimens removed for cancer of the lung, with particular reference to blood vessel invasion. He has found a great number of cases of blood vessel invasion, but particularly adenocarcinomas. As a matter of fact, in every case of carcinoma of the lung with the histologic classification of adenocarcinoma, there has been definite blood vessel invasion. I also wish to bring to your attention the fact that in prognosis of cancer of the lung, the histology is extremely important, and you will notice in Dr. Burford's figures there was an extremely high mortality rate and very poor survival rate in the adenocarcinoma group. I think one should take these things into consideration by doing very careful studies including neurological examinations, electroencephalograms, and bone surveys when one suspects an adenocarcinoma of the lung. In addition to this, as to the specific technique at the time of operation, one should respect these tumors, manipulate them as little as possible and, as a matter of fact, one should make every effort in all cases of carcinoma of the lung, but particularly adenocarcinoma, to first isolate the veins and ligate them before any manipulation of the tumor itself.

I would like to ask Dr. Johnson whether, in his experience with the blood vessel invasion cases, the adenocarcinomas have had such a high invasion rate as we have found at Mt. Sinai Hospital.

DR. ALFRED HURWITZ, Brooklyn, N. Y.—I rise solely to take mild issue with Dr. Burford on one aspect of his discussion when he implied that other than the overt, surgeon-induced complications, surgery for carcinoma of the lung can do no harm. Unfortunately, I have had a few patients whose postoperative course has been characterized by the rapid development of disseminated metastases and death. Some of these patients have been followed by their physicians for 2 to 4 years and have had minimal symptoms and little if any change in the size of their lesions. Rigler has described some interesting cases of bronchogenic carcinoma where there has been little or no change in size on x-ray for as long as 5 and 6 years. Paulson discussed our present dilemma and pointed out that it would be a great boon to mankind if we could develop some biochemical test which would help us to decide which patients would react adversely to surgery and which ones would be benefited by excisional surgery. I am convinced that at times we may destroy the patient's biologic resistance or state of predeterminism which he may have amassed over a long period.

I also noticed one omission in all three papers. None of the speakers discussed their criteria for defining operative mortality. I hope they will define what they mean by operative mortality.

DR. IRVING A. SHORT, New York, N. Y.—In 1934, Dr. Rabin and Dr. Neuhof called attention to the fact that carcinomata of the lung which appeared as circumscribed shadows on the roentgenogram were much more likely to be operable than those which did not produce a discrete circumscribed shadow. My study, in 1941, confirmed this observation.

The question has arisen as to what influence the microscopic cell type has on operability. This was studied in a series of 426 consecutive cases by Drs. Ragin, Schein, Rubinstein, and myself. There were 117 circumscribed tumors and 309 non-circumscribed ones.

Although the cell type does influence operability, the circumscribed tumors are much more apt to be operable in each cell type. Thus, in the mature squamous carcinoma, which is the most favorable, the percentage of operability of the circumscribed tumors was twice as great as the non-circumscribed ones. The difference was even more striking in the tumors of the less favorable cell types, namely, the immature squamous, adeno-, anaplastic, and small cell carcinomas. In these types, the ratio was 6 to 1 in f [illegible] f the [illegible]umscribed tumors.

It must be concluded that the circumscription of the growth is a more accurate index of operability than the cell type.

DR. WILLIAM G. CAHAN, New York, N. Y.—Dr. Graham showed that it was possible to cure cancer of the lung by surgery. Long-term survivals have been reported, not only after simple pneumonectomy but after lobectomy and wedge resection as well. This suggests that there must be various elements in survival apart from the magnitude of the operation. Nevertheless, in 1949, I wondered if there would be any improvement in chances of cure if the mediastinal lymph nodes were added to pulmonary resection as part of radical lobectomy or radical pneumonectomy.

At the 1951 meeting of this Association, as a group, we presented the rationale and step-by-step technique of our version of a radical pneumonectomy. This block dissection was based upon principles of cancer surgery elsewhere within the body. It seemed particularly applicable to lung cancer, for pathologists had been unanimous in describing mediastinal lymph nodes as being the most frequent sites of metastasis, regardless of size, position, and histologic type of the primary tumor.

At Memorial Center, we have performed 150 radical pneumonectomies and over half of these were done by residents as their first pneumonectomy. It is too soon to evaluate the procedure thoroughly, particularly in the light of variables that surround the behavior of lung cancer. After all, radical mastectomy is still controversial after 60 years! But we have been puzzled by certain attitudes about the mediastinal nodes at the time of thoracotomy. Why, for example, do some surgeons still rely upon palpation as the sole method of detecting the presence or absence of metastases? Why do others select a mediastinal lymph node for frozen section and, if this proves to be positive, assume all is hopeless; or if it proves to be negative, consider further lymphatic dissection needless? They would certainly not apply these principles to an abdominoperineal resection or radical mastectomy, for example.

Now it is said that venous invasion may be more significant in prognosis than lymph node involvement, but this may be said also to be true of other sites of cancer, and yet no lesser procedure is performed. In any event, unless grossly evident, venous invasion can only be found in the postoperative specimen and, as such, it cannot in any way influence the type of procedure performed; whereas lymph nodes may be excised or left behind. In addition, we have seen survivors of 5 or more years who have shown blood vessel invasion in the excised specimens, but we know of no such survivor where proved positive mediastinal lymph nodes were allowed to remain. Remember, positive lymph nodes left in situ are not dormant; they can serve not only as sources of invasion, but are capable of giving rise to second generation—or daughter—metastases as well.

The crux of the problem is to determine whether there are significant numbers of long-term survivors in those who have positive mediastinal lymph nodes removed, lymph nodes that would be left behind if a less extensive dissection had been performed. There are several patients in this category now and they will be reported later.

We cannot solve this by rhetoric; we cannot insist, or say with conviction, that the inclusion of lymph nodes is a worth-while addition to a lobectomy or a pneumonectomy, but by the same token no one can say we are wrong.

DR. JULIAN JOHNSON, Philadelphia, Pa.—The question was asked about blood vessel invasion in adenocarcinoma. It was 81 per cent in our series. It was 100 per cent in the undifferentiated tumors. The question was asked regarding a definition of operative mortality. If the patient died within 1 month of his last operative procedure, it was reported as an operative death.

I would like to point out that we quoted Watson's work so extensively simply because his were the best results we could find for radical pneumonectomy. I hope it is clear that it is not our desire to talk any group out of the use of radical pneumonectomy in the treatment of cancer of the lung. We only wish to show that the thoracic surgeon need not feel obligated to perform a radical pneumonectomy as opposed to the standard resection for cancer of the lung, as judged by the 5 year survival data at present available

DR ALTON OCHSNER, New Orleans, La —I am extremely happy to speak this morning for two reasons First, because this session is dedicated to the memory of Evarts Graham I was fortunate in being a senior student at Washington University when Evarts came to Washington as the new Professor of Surgery Evarts and I became very close friends and he used to chide me a lot because I thought there was a very definite causal relationship between smoking and cancer of the lung It was not until a number of years later that he became convinced that there was a relationship, and in his typically honest way he wrote to me and said, "I am going to have to eat crow. I think you are right."

This morning I would like to discuss some of the factors which might influence prognosis in bronchogenic cancer (slide) Unfortunately, our results are not as good as those which have been reported We have had 47 5 year survivals, and I would like to call attention to the fact that sex apparently plays a role As you can see, 268 patients who were operated upon 5 years previously did not survive; the male female ratio was 8 2, whereas in the 5 year survivors the male female ratio was 4 8. So that, although carcinoma of the lung is relatively infrequent in women, when it does occur in women it offers a better prognosis

Also, age in our series was of prognostic importance. Of the 5 year survivors, 38 per cent were less than 50 years of age, 61 or 62 per cent were between 50 and 70, and there were no 5 year survivors beyond the age of 70 In contrast, in the over all group only 21 per cent were less than 50, 68 per cent between 50 and 70, and 10 5 per cent beyond 70.

The type of lesion, as someone mentioned, is a factor Whereas 48 8 per cent of those not surviving had epidermoid carcinomas, 68 per cent of those who did survive for 5 years had epidermoid carcinomas, and the prognosis is worse in the adenocarcinoma group, only 8 per cent of all our 5 year survivors had adenocarcinomas

(slide) It is a well known fact that lesions of the lower lobe offer a worse prognosis and that they tend to metastasize Until recently, these metastases were thought to be blood borne, particularly those of the suprarenal. Dr. Kenneth Meyer, one of my associates, working in the Laboratory of Anatomy at Tulane, has shown that there are definite lymphatic connections between the lower lobes of both lungs and the lymphatics below the diaphragm, to the suprarenal gland. This shows it in the right lung, this shows it in the left lung

So there is a definite lymphatic connection between the lower lobes and the lymph nodes of the abdomen. We have had a total of 1,453 cases, of which 44 per cent were inoperable There were 818 considered operable We cannot talk these people into being operated upon as well as they can at Barnes Hospital, as you see 7 per cent of our patients refused surgery. There were 759 patients explored, which is 52 per cent of the entire group There were 282, or 37 per cent of those explored, who were found to be nonresectable, with a 20 per cent mortality rate That 20 per cent mortality does not represent the exploration but it represents the extent of the disease There were 477 resected, which is a little less than one third, with again a 20 per cent mortality rate In all the survival studies, the hospital deaths are included.

The resectability incidence has distressed me a great deal You can see that from 1914 to 1956 there has been tremendous variation in resectability incidences In 1944 we had our low resectability incidence of 18 8 per cent It then increased, as one would expect, because with the information that cancer of the lung was a common disease and should be diagnosed more frequently, in 1948 we had an all time high of 47 per cent. Then there was an almost progressive downhill trend in resectability incidence until 1955 when we reached almost an all time low This, I am sure, reflects the fact that about 12 years ago there was a great deal in our literature about viral pneumonitis, [illegible] this [illegible]uccinctly called atypical pneumonitis. But, unfortunately, the medical profession has come to think of atypical pneumonitis as being synonymous with viral pneumonitis, and I am sure that the decrease in the incidence of resectability is due to the fact that these patients were treated for months with a diagnosis of viral pneumonitis when in reality they had a bronchogenic cancer.

As I mentioned, age plays a role in all of our survivals; 38 per cent were under age 50, and 62 per cent were between 50 and 70.

Nodal involvement was also a factor. These are clinical laboratory investigations. Where there is evidence of extension beyond the lung at the time of operation, the surgeon designated it as a palliative procedure. I would like to call attention to the fact that in our series, 42.5 per cent had extension beyond the lung at the time of operation. So that, although these represented extensive disease that extended beyond the lung, this 42 per cent did survive 5 years.

Of the total series, 80 per cent had nodal involvement, 38 per cent had pleural involvement, and 6 per cent had distant involvement. I do not want you to get the impression that we operate upon people who have evidence of distant involvement; we do not. These were people in whom we felt there was no evidence of distant involvement, but who died, and autopsy showed that they did have distant involvement. Of the 5-year survivals, 34 per cent had nodal involvement, and 8.5 per cent had extension elsewhere to the pleura or to the chest wall.

Of our cases, 34 per cent of the survivors had nodal involvement and 66 per cent no nodal involvement.

(slide) This is the recapitulation of what I have given you. In those in which the lesion was limited apparently at the time of operation, 32 per cent are alive after 5 years; of all the resections, 15 per cent, and in those in whom there was extension beyond the lung of some type, 9 per cent. One must consider this in the light of the mortality rate in the general population; at this age only 85 per cent of these people in the general population are alive after 5 years. I feel that, after a period of 3 years, the decrease in the survival rate is almost entirely due to other causes rather than carcinoma of the lung. So I think one can say, as Dr. DeBakey and I called attention to a number of years ago when we made our first survival report—about 10 years ago, if a patient is alive and well at the end of 3 years, following extirpation therapy for bronchogenic cancer, his chance of living without evidence of disease is good. We have had 2 patients who have developed carcinoma in the opposite lung after their 5-year survival. These are the only 2 patients who did not discontinue smoking.

CORONARY HEART DISEASE AFTER TWENTY-FIVE YEARS

Claude S Beck, M D , Cleveland, Ohio*

It is an honor for me to present this paper on this part of the program designed to commemorate Dr Evarts Graham There is no other place more appropriate to honor Dr Graham than at this meeting It is our pleasure to think of him today and it is easy to imagine him sitting here in the first row of seats listening intently to everything that is said, with the speaker watching him to see how he is reacting

Although he is not here, he will live with us for many years because he created so many memories that have enduring value He had a positive dynamic mind a restless curiosity, a strong body which enabled him to work and, in addition, he had the courage and the power to speak out for those things in which he believed—these were some of the qualities that made him the great surgeon that he was His contributions are of such value that he will live long in the annals of medical history

INTRODUCTION

The history of coronary heart disease, the world s greatest killer, may be divided into three periods identified as follows (1) by the correct location of the disease, (2) by the electrocardiogram, and (3) by the recognition of the axiom for treatment The fourth period of questionable realization, is that of prevention and retardation of the disease

CORRECT LOCATION OF THE DISEASE

This was accomplished in the 1912 1918 period[1] when the seat of the disease was moved from the stomach to the heart This was done not without opposition from the medical profession By present day standards this should not have required deep thinking In that period there were great internists and pathologists, and *necropsy examinations were not uncommon* But then, as now, the medical profession knew so much that was not so It was of elemental importance to find the correct location of the disease but this did not change treatment "Therapy had not progressed much beyond that used during previous centuries, consisting almost exclusively of rest and sedation "[2] To this has been added the use of anticoagulants There exists a strange complacency toward this disease There is no relationship between treatment and

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*Professor of Cardiovascular surgery Western Reserve University Cleve death. There is no responsibility for death. This futility has paralyzed the thinking and has created the belief that to do nothing more than the old routines is to make no mistake. Nowhere in medicine is there such intellectual emptiness as exists in the understanding and treatment of this disease.

THE ELECTROCARDIOGRAM

The electrocardiogram has disguised this vacuum and has given respectability to the knowledge of the subject. The electrocardiogram has risen to great heights in the erudition of this disease whereas blood supply to ischemic muscle is dwarfed into nothingness. This false relationship in values enabled the electrocardiogram to dominate the picture of the disease. It has even enabled it to pass as therapy. Many a patient believes it helps him because his physician takes so many of them. He knows they are expensive. Little does he know that they were not designed for treatment. Someone should speak out against unnecessary usage of the electrocardiogram and place it in its proper relationship to the augmentation of blood supply to ischemic muscle. Is this not an obligation of the medical cardiologist?

AXIOM OF THE DISEASE[3]

After a coronary artery is stenosed or occluded, the fate of the patient depends upon the amount of blood in the ischemic muscle formerly supplied by this diseased artery. Addition of blood preserves life; subtraction of blood destroys life. This is the elementary starting point for effective treatment and it has been almost entirely disregarded. It may be assumed that several of the medicaments, because they temporarily relieve pain, do temporarily provide blood to ischemic muscle. However, there has been little or no proof of this until recently when trinitroglycerine was tested in the author's research laboratory. Furthermore, there is no evidence to indicate that any of the medicaments change the anatomy of the crippled coronary circulation or that they make intercoronary communications. For long-term protection, therefore, medical therapy fails to develop collaterals which are the requirements of protection when either stenosis or occlusion of an artery develops.

PREVENTION AND RETARDATION

The contemplation of the period when arterial disease in the heart can be prevented or retarded produces an aura of greatness. If it can be prevented in the heart no doubt the same biologic principles will prevent it in the brain, extremities, and elsewhere in the body. Next to food, shelter, and the absence of war there is probably nothing more important. On a practical and realistic basis, however, prevention should not be confused with treatment. Between these two there is no relationship. The expectation of good things to come also contains the possibilities of slow progress or even failure. Expectation is no solace for the status quo in treatment. Society has a right to demand that methods for effective treatment be investigated now. Society has not been informed of the ineffectiveness of long-term medical therapy.

CONTRIBUTIONS FROM THE LABORATORY[4]

These are based upon approximately 6,000 experimental operations on dogs in the past 25 years. The motivation of these experiments was to improve the crippled coronary circulation. While this was a guide in this work, physiologic concepts were also brought into being which explain the benefit produced by the experiments. Also the facts from the laboratory shed light on some of the clinical aspects of the disease. For example, the three death factors of the disease were given definition and the requirements for treatment of each death factor were brought under scientific scrutiny. The reversible nature of one of these death factors was defined and reversibility from death to life was accomplished in several human beings who had died from the disease.

Some of our experimental work has little or no application to treatment at the present time and this part of the work is omitted from this presentation. This includes the work on retrograde flow by placing a graft between aorta and coronary sinus. This approach protects the heart more than any other procedure that we developed, but it has certain side effects which are unfavorable and the operation of placing this graft is a difficult technical procedure. Important physiology was established by this work even though it may not have application to treatment of this disease at the present time. The work on the direct manipulation of the coronary arteries themselves such as cleaning them out or placing shunts or grafts in them is also omitted as impractical at the present time. These contributions from the laboratory are referred to briefly.

1. *Blood supply to ischemic muscle is the axiom for treatment.* When a ligature is placed around the origin of the descending ramus of the left coronary artery, 5 c.c. of blood per minute delivered to this occluded artery will preserve the heartbeat in the dog. Additional blood gives additional protection. Reduction has the opposite effect. This amount of blood does not support contractility of muscle nor does it prevent infarction but in a large series of dogs it preserves the heartbeat. As stated above this axiom is nothing less than the elementary starting point for effective therapy.

2. The electrical condition of the heart in relation to its oxygenated blood supply was investigated and four facts were established. In these experiments the heart was exposed and electrograms were taken from its surface by sweeping a cotton electrode moistened in sodium chloride solution across the ventricles. The following facts were established.[5]

a. A uniformly well oxygenated heart is electrically stable. The pattern of the electrogram is the same from any part of the ventricles.

b. A uniformly and deeply cyanosed heart is electrically stable. Cyanosis is produced by clamping the intratracheal tube in the anesthetized dog. The pattern of the electrogram is the same as in "a." The cyanosed heart does not fibrillate. It stops in standstill. A blue baby has a stable heart. The facts referred to in "a" and "b" indicate that electrical stability of the heart is independent of the amount of oxygenated blood delivered to it. Electrical stability is based upon a uniform distribution of the heart's own blood regardless of the amount of oxygen in this blood. In other words, stability is not related to oxygen content of muscle.

c. Ligation of a coronary artery produces an area of cyanosis in the muscle formerly supplied by this occluded artery. A blue or cyanosed island of muscle is produced in a pink or well-oxygenated heart. The S-T segment of the electrogram is elevated over the well-oxygenated muscle. It is depressed over the cyanosed muscle. This heart is electrically unstable and may fibrillate.

d. A coronary artery such as the descending ramus of the left coronary artery is cannulated. Into this artery, well-oxygenated blood is perfused. The intratracheal tube is clamped and the heart becomes cyanosed except the area supplied by perfused blood. This produces a pink, well-oxygenated area in a blue cyanosed heart. The electrogram is the same as in "c." The S-T segment is elevated over the well-oxygenated muscle and depressed over the cyanosed muscle. This heart is electrically unstable and may fibrillate. A baby with one coronary artery coming off the aorta and the other from the pulmonary artery has anginal pain and an unstable heart which may fibrillate. Two conclusions are established by experiments referred to in "c" and "d." One is that an uneven or checkerboard distribution of oxygenated blood produces electrical instabillity, fibrillation, and death, and these sequelae are produced by ligation of a coronary artery in a well-oxygenated heart or by delivery of well-oxygenated blood into a cyanosed heart. The heart electrocutes itself. The other conclusion concerns a long-standing physiologic concept that occlusion of an artery produces "current of injury." The placement of pink and blue muscle in juxtaposition does not require injury of muscle. The correct term for this is "electrical instability due to oxygen-differentials." Reduction in the degree of oxygen differential makes the heart electrically more stable. Increase in the degree of differential makes the heart electrically more unstable. Current of injury is an incorrect term and expresses an incorrect physiologic concept.

3. When a coronary artery is occluded two distinct and different biologic phenomena occur. One is electrical instability. The other is death of muscle (Fig. 1). One may occur without the other. Both may occur together. Thus, the heart can electrocute itself without infarct. Infarct, even successive infarcts, may develop without an electrical condition strong enough to fibrillate the heart. This separation is essential in order to understand the physiology of the disease and its clinical manifestations.

4. There are two approaches to effective treatment. Both of these conform to the axiom in Item 1.

a. Distribution of the heart's own blood so that a red cell, after it gets by the stenosis in the arteries, can go anywhere within the substance of the heart where it can do the greatest amount of good.

b Addition of blood from outside sources, from grafts on the heart, by retrograde flow through veins, or by cleaning out the diseased arteries themselves or by other manipulations on these arteries On the basis of considerable experimentation, the statement can be made that the heart resists the entrance of outside blood It is not impossible to demonstrate *arteries between graft and heart large enough to carry blood but their* occurrence in experiments is infrequent Perhaps better methods can be developed Direct manipulation of the coronary arteries in my experience has not been successful

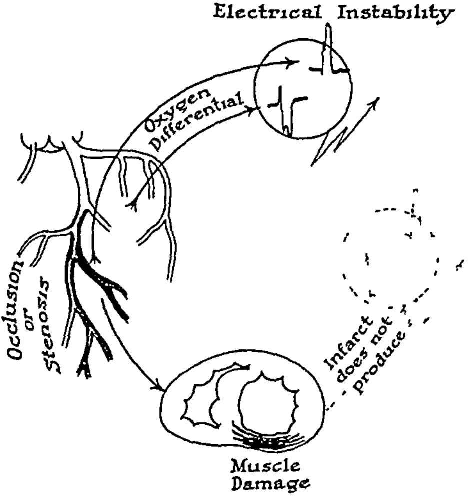


Fig 1—Two sequelae of occlusion or stenosis— (1) muscle damage and (2) electrical instability These responses are independent of each other Viability of muscle is related to amount of blood supply the electrical condition is related to distribution of blood There is no conflict with the science when death occurs without infarct (as on the golf course) or in the presence *of what the clinician refers to as a mild* occlusion The term mild is scarcely correct when it is associated with death and probably should not be used

5 The amount of blood necessary to reduce the sequelae under Item 3 is in the range of several cubic centimeters per minute In the human heart, as in the dog heart, there is always some blood in the ischemic muscle beyond the occlusion The amount is variable and measures several cubic centimeters per minute Quantities in the range of 2, 4, or 6 c c per minute added to that *which is already present reduce the sequelae of occlusion If this fact from* the laboratory were properly appreciated, the opposition to the surgical approach in treatment would be reduced Only the scientist in the laboratory appreciates the value of several cubic centimeters of oxygenated blood per minute delivered to ischemic muscle This lack of understanding is, indeed, an unfortunate condition as it is fundamentally related to effective treatment of this disease

6. Quantities of blood within this range are made available by the production of intercoronary arterial anastomoses and these can be produced by surgical operation. Several procedures contribute to their development. The author's operation consists of abrasion of the lining of the parietal pericardium and surface of the heart, narrowing of the coronary sinus to a diameter of 3 mm., a light application of 5 per cent aqueous solution of trichloracetic acid to the surface of the heart between coronary arteries, light application of powdered asbestos to the surface of the heart, and the application of parietal pericardium and mediastinal fat as a graft to the surface of the heart. Narrowing of the sinus and abrasion of the epicardium are omitted if the heart is irritable at operation.

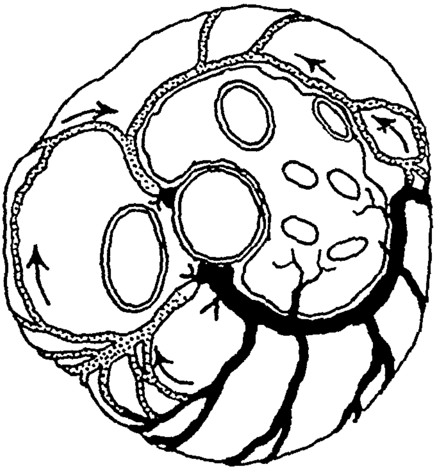


Fig. 2.—Sketch of Hahn-Beck heart. The artery in black is the circumflex ramus of the left coronary artery. It is the only coronary artery that carries in blood and this blood goes through an opening of 1 mm. in diameter. The descending artery and the right artery are occluded. These are stippled and they receive blood from the circumflex by way of intercoronaries indicated by the arrows. Once a red blood cell gets by the stenosis it can go anywhere in the substance of the heart where it is needed most.

7. Operation under Item 6 makes it possible to utilize the heart's own blood in the most effective way. It may not add new blood to the heart from outside sources but it does make more blood available to ischemic muscle from contiguous areas of muscle possessing a good blood supply. The average amount that it adds to ischemic circumflex muscle is 4.7 c.c. per minute or 282 c.c. per hour. The average amount that is already in the circumflex area of muscle after the artery is ligated in normal dogs is 3.8 c.c. per minute. After operation the average amount is 8.5 c.c. per minute. The average inflow into this artery in normal dogs is about 34 c.c. per minute.[6] The amount available after operation and subsequent occlusion, therefore, is approximately 25 per cent of the normal inflow. It is raised by operation from 11 per cent of the normal inflow to 25 per cent of the normal inflow. This is *significant protection.*

8. The normal coronary arteries are capable of delivering much larger quantities of blood than the amount that flows through the capillary bed. As

stenosis of the coronary arteries develops, the first conflict with normal physiology is produced by an uneven distribution of the blood that enters these diseased arteries. Distribution versus amount involves a fundamental concept in physiology. In the dog, all coronary inflow except that which goes through an opening of 1 mm. in diameter in one artery is enough to support the heartbeat and provide normal activity (Hahn Beck dogs)[7] (Figs. 2 and 3). In the human being, an opening of 1.5 mm. in diameter can support the heartbeat. This blood must be evenly distributed in order to support the heartbeat. If it is not evenly distributed, the heart electrocutes itself. As the stenosing process becomes more severe, the second conflict with the physiology appears when there is not enough blood in the substance of the heart to support the heartbeat.

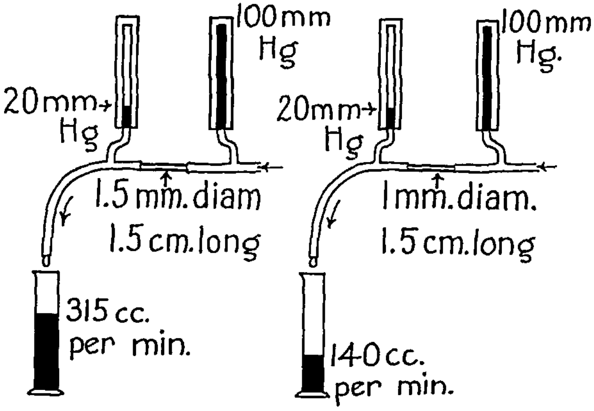


Fig. 3.—Rigid tube systems with stenosis. These flows are sufficient to maintain life. The dog has a flow of about 100 c.c. per minute through the capillary bed and the flow in the human being is about 250 c.c. per minute.

9. The operation under Item 6 has been well tested by the Mautz Gregg backflow measurements,[8] by mortality after test artery occlusion, by infarct size in dogs that recover from test artery ligation, and by electrocardiographic evidence. The average backflow is increased 4.7 c.c. per minute or 282 c.c. per hour. The mortality rate is reduced when a major artery is occluded. For the descending ramus of the left coronary artery at its origin the reduction is from 70 per cent for normal dogs to 26.6 per cent for dogs *in which the heart was previously protected by operation.* The size of the infarct is reduced by 60 to 70 per cent. The electrocardiogram shows fewer and less severe alterations after artery occlusion in the protected dogs. A large amount of evidence indicating protection has been established.

10. There is still another fact concerning the value of several cubic centimeters of blood to ischemic muscle. A critical period exists when an

artery becomes occluded. If the heartbeat is maintained after occlusion for several days or for 1 or 2 weeks then intercoronary channels develop. It can be stated that they always develop *after occlusion and they* are of good size.[9] The blood made available to ischemic muscle by *operation helps to maintain* the heartbeat over the critical period so that nature has time to provide additional intercoronaries. This may be considered as an extra protection, so to speak, *from the operation.*

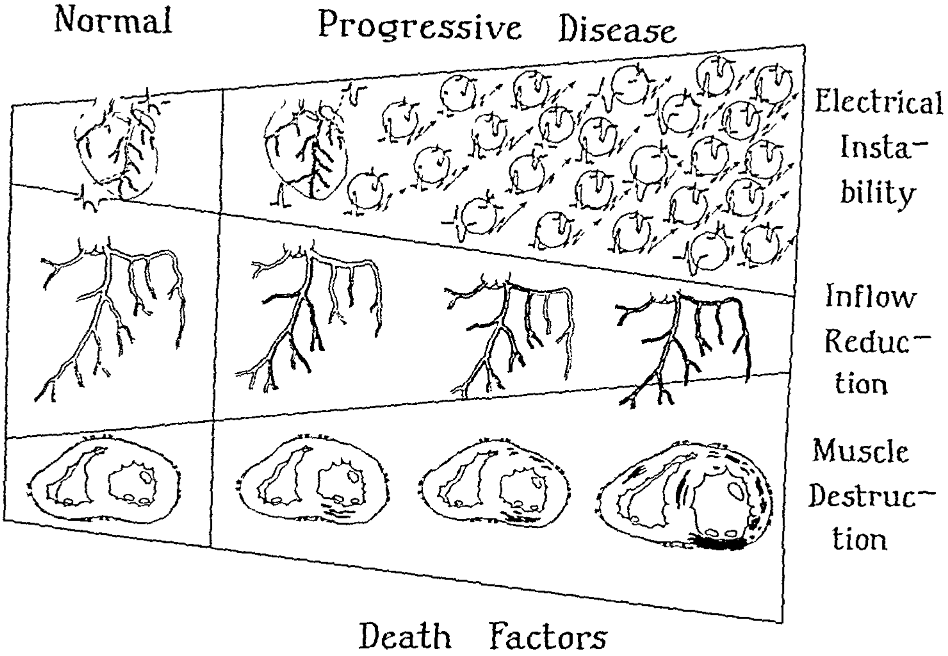


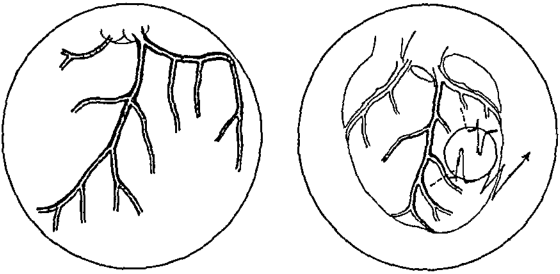
Fig. 4.—Three death factors in coronary heart disease—(1) self electrocution of the heart, (2) terminal stage in reduction of arterial inflow, and (3) terminal stage in destruction of muscle. *Requirements for treatment of each factor can be determined.*

THE INFLUENCE OF THE LABORATORY UPON CLINICAL CONCEPTS

The facts established in the laboratory are not only applicable to the treatment of the disease in the human being but they give some degree of order to the clinical *understanding* of the disease. Of fundamental importance are the three death factors in coronary heart disease (Fig. 4) and the combination of these factors as found in necropsy examinations (Fig. 5).

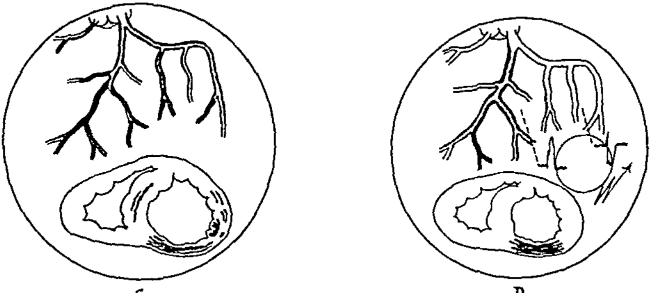
11. One factor of the disease that kills is by self electrocution of the heart. The majority of the deaths are due to this factor. It kills under a variety of conditions, on the golf course, when shoveling snow, when watching an exciting contest, during physical exertion, at rest, etc. In many instances the heart is too good to die. Sometimes this death factor is reversible and life can be restored.[10] The author actually accomplished this in 2 human beings who died from the disease and who are living several years later. If the profession were prepared, no doubt, restoration of life could be accomplished outside the hospital and a large number of lives might be saved.

The term "mild occlusion" is a clinical syndrome often described by the cardiologist. When a patient with a mild occlusion dies the terminology is wrong and a paradoxical situation is created. The term "mild occlusion" is used to refer to muscle damage without reference to the electrical condition that might assert itself. There should be no mystery in this association. Perhaps the term "mild occlusion" should not be used.



A
Inadequate Inflow.

B
Stenosis. Electrical Instability.



C
Stenosis. Occlusion. Myocardial Failure.

D
Stenosis. Occlusion. Infarct. Electrical Instability.

Fig. 5.—Various combinations of these factors are present in the heart. *A*, Inadequate inflow without infarct; *B*, self electrocution without infarct; *C*, muscle failure; *D*, self electrocution with infarct.

12. The incidence of self electrocution of the heart is reduced by the presence of intercoronary communications. This is probably the only death factor for which, at the present time, there exists effective surgical treatment.

13. Another death factor is inadequate inflow to support the heartbeat. The muscle may or may not be severely damaged. There is no effective operation for this condition at the present time. Clinical recognition of this condition is not always possible. Loss of strength and inability to get around may indicate severe inflow reduction.

14. The third death factor is loss of muscle. There isn't enough muscle to propel the blood and failure develops. The heart is enlarged. The only treatment is that for failure. There is no operation for this.

These 14 points convey the author's point of view concerning coronary heart disease. By design these points concern physiology and effective treatment. The origin and development of these points were slanted toward therapy. They break away from the established medical point of view as though a different disease is under consideration.

In this new design, the axiom for treatment displaces the electrocardiogram to a secondary position. The cleavage between the existing superstructure of the disease and this new design is comparable to the break that occurred in the 1912-1918 period. This new design is of equal or greater importance to making the correct location of the disease because it concerns effective treatment and there is no substitute for augmentation of blood supply to ischemic muscle.

EXPERIENCES ON HUMAN BEINGS[11]

The author's operation or some modification of it was done on 347 patients between Jan. 1, 1954, and Feb. 14, 1958. These were consecutive operations done at University Hospitals and Mount Sinai Hospital, Cleveland. Total mortality during the period of hospitalization was 21 or 6 per cent and the total mortality after discharge from the hospital during the period of somewhat more than 4 years was 32 or 9.2 per cent. Within this series were 100 consecutive operations with zero operative mortality, and in the subsequent series of 100 cases, there were 4 patients who died, making the mortality 2 per cent for 200 consecutive cases. The classification of salvage was applied to patients in whom the anatomic disease in arteries and/or myocardium was approaching the terminal stages. The inflow was approaching the critical stage when it would become inadequate for function and the destruction of muscle was approaching the stage when it would be inadequate to pump the blood. This classification of salvage cases was based upon an estimate made at the time of operation. In this group, there were 110 classified as salvage or 32 per cent; 234 were classified as nonsalvage or 67 per cent; and 3 were not classified. According to this classification, one third of the patients operated upon were approaching the terminal stages of the disease when mortality could be expected to occur in the not too distant future.

Many patients are not referred for operation until the disease approaches the terminal stages when the patient is told that medical therapy has nothing more to offer. In the 110 salvage cases, the total mortality during the 4-year period was 26 per cent—hospital mortality 12 or 11 per cent, subsequent mortality 16 or 15 per cent. In the 234 nonsalvage cases, the total mortality during the 4-year period was 10 per cent—hospital mortality 8 or 3 per cent, subsequent mortality 16 or 7 per cent. In the nonsalvage cases, the risk of operation is low, and the life span probably is excellent. In patients with coronary heart disease, this appears to be a good record and emphasizes the desirability of early operation. The death factor in the early stages of the disease is the unstable electrical condition of the heart and operation has proved its value against this factor. The scientist accepts this as a statement of fact.

The heart was examined at operation according to a formula learned by experience. The size of the heart was noted. An enlarged left ventricle indicated myocardial damage. A rolling or rocking motion indicated that the muscle was not contracting in a uniform manner due to the presence of scar. Localized reduction or absence of pulsation indicated localized myocardial damage. Some of the scars did not come to the surface and could not be observed. The anterior and posterior aspects of the heart were observed. In some instances, the heart was irritable and could not be tipped up to examine the posterior surface. The arteries were examined. The common left artery was palpated. The circumflex artery and the right coronary artery cannot be observed or palpated. A soft pulsating common left artery indicated normal inflow. When this artery is soft and pulsating, the problem in therapy is not addition of blood to the heart, but distribution of what is there. A severely thickened or calcified common left artery indicates inadequate inflow. The problem then becomes one of addition of blood to the heart and this cannot be accomplished by surgical operation. The artery must be severely stenosed before inflow reaches terminal reduction. Beading and streaking with atheroma is observed in the descending ramus, its branches and in the branches of the circumflex artery. Pulsation is observed to be normal, reduced, or absent. Irritability of the heart is noted. It sometimes occurs when the heart is manipulated but it was observed in 1 case when only the pericardium was picked up in a hemostat prior to opening it. The heart almost fibrillated when the pericardium was gently grasped in a hemostat. Indeed, grasping only the pericardial fat in a forceps almost fibrillated the heart. Marked irritability is a danger signal, and is considered an indication for a modified procedure such as the application of 5 per cent freshly diluted aqueous solution of trichloracetic acid to the surface of the heart between coronary arteries, and a light application of powdered asbestos to the surface of the heart. Marked irritability indicates severe inflow reduction. It is not necessarily associated with severe muscle damage. Indeed the heart with extensive myocardial infarcts is often stable, probably due to the presence of *intercoronaries which developed after arterial occlusion.*

Examination of the heart at operation does not reveal all of the anatomic disease that actually exists in arteries and muscle. Some of these manifestations are found only at necropsy examination. The beating heart, however, gives some information not obtained by necropsy examination. The localized absence of pulsation and the outward bulge of an aneurysm are detected when the heart is beating. Any outward bulge of the heart, even though slight, was classified as an aneurysm. Analysis made at the time of operation is as follows: Size of the left ventricle, normal 221 or 64 per cent, enlarged, 126 or 36 per cent, aneurysm, 37 or 11 per cent [illegible] farct

250 or 72 per cent; no visible infarct, 97 or 28 per cent; arterial disease observed, 332 or 96 per cent; not observed 14 or 4 per cent; common left artery palpated, soft, and pulsatile, 261 or 76 per cent; thickened or calcified, 81 or 24 per cent.

According to this analysis, the hearts operated upon showed positive and usually severe manifestations of coronary heart disease. When a patient died and the heart was examined, the disease always was more severe than anticipated by the examination at the time of operation. When the heart stopped beating, complete recovery was possible in only 1 patient. This heart fibrillated 4 hours after operation and continued to fibrillate during a period of 35 minutes while the heart was being pumped by hand. This patient is alive more than 1 year after operation. In the other patients who died during operation, it was sometimes possible to restore the beat for periods of minutes or several hours, but always the heart went back into fibrillation. In some of these patients, the chest was opened, the heartbeat was restored, the chest was closed, the heart again fibrillated, the chest was opened, the beat was restored, and so on. One patient between these temporary deaths stated that she did not like the electric shocks, that she thought they were only for psychiatric patients. We worked on some of these patients as long as 16 hours and opened and closed the chest as many as four times. During these hours, the patients made conscious responses and understood what was stated. In several of these patients, an attempt was made to scrape out athermomatous deposits in the descending artery. This was never successful. In my opinion, this procedure has little to offer in treatment of this disease. When the common left artery is soft and pulsatile, the assumption is made that the inflow of blood into the heart is adequate and the problem in treatment is distribution of this blood rather than addition from other sources. The author's operation is designed to distribute this blood. Three out of 4 patients had a soft pulsatile common left artery and this was interpreted to mean a more favorable operative result.

A low operative mortality is necessary in order to make the operation acceptable. Coronary heart disease in any stage of its development kills as does no other disease. Death occurs with or without operation, but when associated with operation, then the latter assumes a causal relationship. In order to have a low operative mortality, it is necessary to be selective with patients for operation. Cardiac failure and marked enlargement of the heart are contraindications. Severe inflow disease is another contraindication. This occurs with or without muscle damage. Clinical recognition of this condition is often not possible, especially if the heart is of normal size, and there is little or no evidence of infarcts. Status anginosus and incapacitating pain may indicate severe inflow reduction, but some of the best clinical results were obtained in patients with incapacitating pain who tolerated operation satisfactorily. Recent activity of the disease, as indicated by a recent infarct or by an unusually severe attack of pain, is an indication to delay operation for several months, and 5 out of 8 patients in whom this was done, died during the waiting period.

In the past 2 years, the policy was established to withhold operation on patients whose blood pressure under anesthesia fell to 90 mm Hg and did not spontaneously rise again without the use of drugs This occurred in 14 patients in whom operation was not done and 3 of these died sometime later Operation was refused to 15 patients because of severe disease determined after study in the hospital and 4 of these died subsequently There is some danger in operating on any patient with coronary heart disease, but there is a group of patients in whom it can be stated before operation that the risk is slight In the group with severe disease, but acceptable for operation, it is sometimes not possible to recognize those with marked inflow reduction A "bad case" clinically may be a "good case" at operation and vice versa

CLINICAL RESULTS

A survey of clinical results was completed recently In this series of 347 patients there are 295 patients who are still living Each of these patients was contacted by office visit, by telephone, or by questionnaire The definition of excellent was applied to those patients who were completely or almost completely free of pain and took no medication after operation The definition of good was applied to those patients who were improved after operation but had an occasional pain and took significantly less medicament The vast majority were back to work Of the entire group of living patients, 278 (94 per cent) received an excellent (32 per cent) or a good (62 per cent) result In the group of 73 living salvage patients, the results were almost as good as in the entire group, with 22 per cent receiving an excellent result These figures are such that the accuracy of the analysis might be questioned They might appear to be too good and, therefore, not acceptable These results were carefully compiled It is possible for the operation to produce a biologic response in every patient in whom it is done and this in turn produces benefit in every patient operated upon Another factor for consideration is that death removed some of those patients in whom the disease was progressing and this gave some selectivity to this group Another factor, which is present whether the patient is treated by medical measures or by surgical operation, is the mental overlay associated with this disease This factor is important but it should not be overrated There probably are not many patients who, having gone through the discomfort of operation, would persist in saying they were better over a period of months or years if they were not better

Many patients state that the anginal pain disappeared as early as 2 days after operation These patients complain of incisional pain but state that the "old pain" has disappeared This can be explained on the basis of improvement in the coronary circulation brought about by the inflammation on the surface of the heart occurring as early as several days after operation The results in patients who had severe anginal pain before operation are almost unbelievably good It is almost necessary to talk to these patients to appreciate the result

There are several objective signs of improvement after operation. In 1 patient, the radial pulse on the left disappeared after coronary occlusion. This pulse was absent until operation was done 1 year later. On the second day after operation it was discovered that the radial pulse was present. Many patients state that they are warmer after operation. A study of skin temperatures of the feet was carried out and it was shown that if the feet were cold before operation, they became warmer after operation. The average rise in 11 patients was 7° C.[12] This is an objective (not subjective) change following operation.

Several other objective changes occurred after operation. In 11 patients, the chief complaint before operation was irregularity of the heartbeat due to ventricular premature beats or atrial premature beats. Several patients had episodes of sinus tachycardia.[13] These conditions were alarming to the patient. They improved or disappeared after operation. Ballistocardiograms were carried out on many of these patients. An abnormal ballistocardiogram was found in 10 out of 17 patients before operation. The ballistocardiogram in 8 of these 10 patients was improved after operation.[14] This was interpreted as improvement in the contractility of the myocardium and is a good correlation with the clinical improvement.

EFFECT OF GLYCERYL TRINITRATE (NITROGLYCERINE) ON BACKFLOW

Some of the drugs used in the treatment of coronary heart disease are being tested in the author's research laboratory by Dr. David S. Leighninger.[15] The same tests that were applied to the author's operation are being applied to these medicaments. So far, backflow determinations of the effect of nitroglycerine were done on 21 dogs. These tests were done as follows. The circumflex artery is ligated near its origin. The artery is transected distal to the ligature and a cannula is introduced into the artery. This cannula is connected to the carotid artery by a tube. Perfusion from this artery is stopped and the cannula is opened so that blood can escape from the distal circumflex artery. The mean aortic pressure is maintained at 100 mm. Hg. The blood that escapes is a measure of the amount of blood coming to the circumflex area of muscle by way of intercoronary arterial communications. The flow is measured for 30 seconds and is expressed in drops or cubic centimeters per minute. After a determination is made, the circumflex area of muscle is again perfused from the carotid artery. The backflow is determined by taking the average of several determinations made at 5-minute intervals. Nitroglycerine is then given intravenously and measurements are again made while the drug is effective. The mean increase in backflow was 0.8 c.c. or 12 drops per minute. The range in the experiments was 0.2 to 5.4 c.c. per minute. The duration of drug action was approximately 5 to 10 minutes.

These determinations are a measure of the most effective drug in the treatment of anginal pain. They are almost the only direct measurements of this drug-action on blood supply to ischemic muscle. It is indeed a strange commentary that this information, after years of usage on patients, originated from a surgical laboratory by a surgeon who has had experience with this test. Without this experience, these positive measurements probably would have been missed or considered insignificant. The relief of pain is based upon 12 drops of blood per minute to ischemic muscle. The author's operation adds 4.7 c.c. per minute or almost 6 times this amount. The effect of this drug lasts 5 to 10 minutes. Then the backflow returns to normal. The increased backflow following operation is not temporary. It is permanent. These measurements probably place the effectiveness of operation in a new light.

CONCLUSIONS

1. A new design for the physiology and treatment of coronary heart disease has been created. This design concerns blood-supply to ischemic muscle and not the electrocardiogram.

2. Three death factors of coronary heart disease are defined. The requirements for treatment of each are given. One death factor is preventable. It is also reversible.

3. The important concepts of the disease are as follows:

a. The axiom.
b. Two approaches in treatment concern, (1) addition of blood to the heart, and (2) distribution of the blood that gets into the coronary arteries.
c. An uneven distribution of the heart's own blood is responsible for most of deaths from the disease and not an inadequate total inflow.
d. A uniformly cyanosed heart is electrically stable. The amount of oxygenated blood delivered to the heart is not a factor in electrical stability.
e. Well-oxygenated blood delivered into one coronary artery of a cyanosed heart can destroy the heartbeat. Red blood can kill the heartbeat under certain conditions.
f. A cyanosed area of muscle (as produced by arterial occlusion) in a well-oxygenated heart can destroy the heartbeat.
g. An uneven distribution of blood produces death by self electrocution.
h. The two sequelae of occlusion, (1) death of muscle and (2) electrical instability are not related.
i. Quantities of blood in the range of drops or several cubic centimeters per minute delivered to ischemic muscle are beneficial and protective.
j. Operation can produce intercoronary communications.

These concepts are poorly understood. It is the author's opinion that coronary heart disease is as poorly understood at the present time as were the bacterial diseases before Pasteur. The statement is sometimes made that "it is good to get your coronary occlusion and have it over." This statement is reminiscent of the expression "laudable pus" before Lister.

4. Nitroglycerine augments the amount of blood in ischemic muscle by about 12 drops of blood per minute in the dog. This drug effect lasts 5 to 10 minutes. It is suggested that the term *nitroglycerin unit* be used to relate these

laboratory measurements with the clinical effect of this drug. This unit, as such, combines clinical effect and quantity of blood and could be used in reference to other drugs and surgical operations.

5. The author's operation delivers several times this amount and this blood supply is permanent.

6. Results of operation are excellent or good.

If Evarts Graham were here he would have the mind to understand this work, and, second, he would have the courage and the spirit to fight for its application to patients. This work should not be allowed to remain as a second Semmelweis episode.

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DISCUSSION

DR FREDERICK R MAUTZ, Cleveland, Ohio —It is a great privilege to discuss the paper of my good friend and long time colleague, Dr Claude Beck, on this program honoring Dr Evarts Graham

I want to review briefly the physiologic basis for the Beck procedure We believe that the dog heart provides information comparable in every way to the situation in the human heart In the normal heart, the coronary arteries are pretty much end arteries but almost always show a considerable network of fine intercoronary arteriolar anastomoses

When we isolate a major arterial ramus in a functioning heart as, for example, the circumflex branch, ligate and distally divide the artery, we note a little back bleeding of bright red arterial blood from the peripheral cut end This blood has traversed the intercoronary anastomotic channels On first appearance this seems to represent a very slight amount of collateral but, as we study a large number of preparations, we find a wide variation in the backflow In a group of 52 normal dogs this varied from 0 1 c c/min to 22 c c/min In a comparable series of dogs that had previously had a Beck I procedure done, the backflow varied from 1 c c to 27 c c/min, the average being twice that of the normal hearts In both groups, this backflow represents a basic intercoronary collateral in hearts that have had *no previous arterial obstruction*

If we add the factor of chronic arterial obstruction we find great increases in the backflow in the majority of experiments, on occasion exceeding 100 c c/min of arterial blood Peripheral coronary pressures in such preparations occasionally approach aortic pressure whereas peripheral coronary pressure in the normal heart varies from 1/4 to 1/3 of mean aortic pressure The increase has been shown to be due to enlargement of intercoronary arterial channels which have become capable of providing a functional collateral circulation from unoccluded coronary arteries

The surgical procedures of the Beck I operation, namely, abrasion of the epicardium, narrowing of the coronary sinus, and the application of powdered asbestos, cause an increase in the basic intercoronary anastomoses and also aid in the natural process of gradual enlargement of anastomoses due to the factors of inflammation plus a mild degree anoxia due to reduced venous blood flow The result is a more uniform distribution of arterial blood in the myocardium Our studies seemed to indicate that extracardiac sources of blood are not tapped until quite late Some recent studies of Lord and associates of New York, using a method of extracorporeal circulation, report what I believe are the first direct measurements of extracoronary collateral, and obtained values as high as 10 per cent of the control coronary flow measurements

I am confident that this door of Nature has now been opened [illegible] not [illegible]o we have reached the ultimate in our understanding of the phe [illegible] ure dealing. Let us further develop our principles of treatment and continue to be guided by the spirit of Dr. Graham in our quest of facts. We must study, measure, and prove the facts in the laboratory before we indiscriminately try to apply new procedures on man.

DR. A. VINEBERG, Montreal, Canada.—I wish to congratulate Dr. Beck on his wonderful work which has been carried out over a great many years, in spite of much opposition and terrific odds.

There now remains little doubt that partial ligation of the coronary sinus opens up intercoronary collaterals and provides better distribution of the blood that has managed to reach the heart muscle beyond the points of narrowing in the coronary arteries. However, there is absolutely no experimental evidence that extracardiac blood ever reaches an ischemic heart following the Beck I operation. Further, during all these years, no injected human specimens have been presented to show arteriolar-sized channels between pericardium and myocardium. The ever-changing character of coronary artery heart disease and the variations in the selection of patients for treatment make the evaluation of any method difficult. For this reason the ameroid method of experimentally constricting

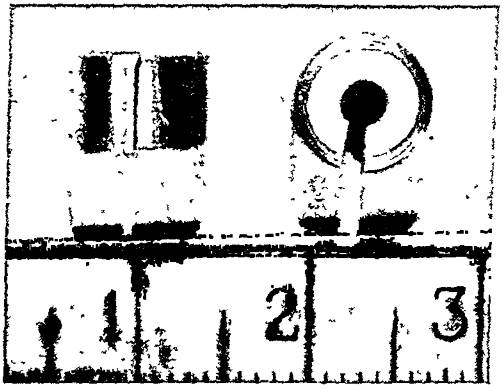

Fig. 1.—Photograph of casein ameroid with steel housing showing slot through which artery passes into central hole.

TABLE I. CORONARY ARTERY AMEROID CONSTRICTION TEST OF MYOCARDIAL REVASCULARIZATION PROCEDURES*

OPERATIVE PROCEDURE	NO. OF ANIMALS	DEAD UNDER 30 DAYS	SACRIFICED DUE TO ILLNESS	SURVIVED	
				4 WK. TO 4 MO.	6 MO. OR LONGER
Control	22	19 (86%)	2 (14%)	1	0
Beck I	10	9 (90%)	0	0	1 (10%)
Cardiopneumopexy (Harken)	10	9 (90%)	0	0	1 (10%)
Ivalon tube, aorta to ventricle, all grafts blocked	12	11 (92%)	0	0	1 (10%)
Internal mammary and subclavian artery ligation	8	8 (100%)	0	0	0
Internal mammary artery implantation only—of which 18 arteries were open	19	0	0	13 (68%)	6 (32% [open])
Internal mammary artery implantation + Coronary sinus ligation	10	0	0	3 (30%)	7 (70%)

*In all animals, petrolatum-coated ameroid constrictors were placed around anterior descending and circumflex branches of the left coronary artery.

coronary arteries has been developed in our laboratory Constricting ameroids (Fig 1) are placed around the origins of both the anterior and circumflex branches of the left coronary arteries These slowly absorb water and gradually narrow the coronary vessels so that all control animals die under 30 days or have to be sacrificed, due to illness, within 6 weeks The lumina of the coronary vessels are reduced to about 20 per cent of their

Fig 2—Filling anterolateral wall left ventricle by injecting Schlesinger mass into 2 month old implanted internal mammary artery in animal which died from ameroid constriction of anterior descending and circumflex arteries

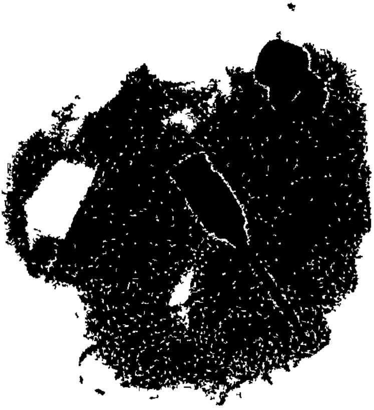

Fig 3

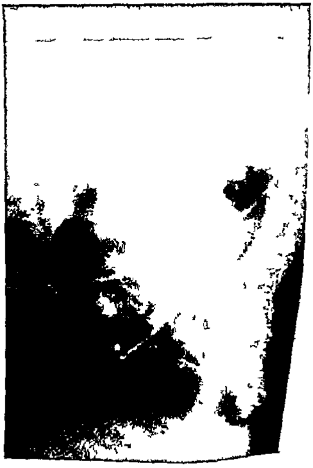

Fig 4

Fig 3—Filling of entire left ventricular coronary arteries through inter[illegible] artery placed in heart 6 months before in animal that survived ameroid [illegible] anterior descending and circumflex arteries

Fig 4—Animal 151 Angiocardiogram of left ventricle filled through [illegible] ternal mammary implant showing mammary coronary anastomoses and fi[illegible] arterioles Anterior descending coronary artery completely blocked circ[illegible] 80 per cent occluded

normal size. Extensive intercoronary collaterals form, but not in sufficient size to prevent death. The control animals die suddenly during fights, after eating, or while exercising. With this standardized technique, it is possible to objectively evaluate methods of treating coronary artery insufficiency. It is quite clear that any procedure that prevents death and infarction when the two main branches of the left coronary artery are narrowed or occluded should be worth while. The surgical techniques tested by Dr. B. Mahanti this year are listed in Table I.

There were 22 control animals; the majority died under 30 days, 3 survived less than 6 weeks and were sacrificed due to illness.

It is interesting to note that the Beck I operation, cardiopneumopexy as done by Harken, and Ivalon tube grafts from aorta to myocardium failed to prevent death except in 10 per cent of a total of 32 animals. Internal mammary artery implantation alone, in 19 animals, provided some protection in 13 of the animals which lived 4 weeks to 4 months. Of these, there were twelve open internal mammary arteries, but mammary coronary anastomoses were limited to the anterior ventricular wall (Fig. 2). Of the remaining 6 animals, all the internal mammary arteries were open, all lived 6 months or more, could not be killed by exercise, and all showed extensive mammary coronary anastomoses involving the entire left ventricle (*Fig. 3*). When partial ligation of the coronary sinus was performed simultaneously with internal mammary implantation, 8 of 10 animals had open arteries. Three animals died 4 weeks to 4 months afterward but 7, or 70 per cent, lived 6 months or more. All internal mammary arteries were open and showed extensive mammary coronary anastomoses. Further, *the left coronary arteriolar bed was satisfactorily filled through the internal mammary artery* by angiocardiogram (Fig. 4). Since obtaining this experimental evidence, internal mammary artery implantation and coronary sinus ligation have been performed on 2 human beings.

DR. JOHN STRIEDER, Brookline, Mass.—Surgical approaches to chronic coronary artery disease have been a leading topic for many years. The treatment of coronary occlusion during the acute phase by removal of the obstruction to flow, and support of the circulation by extracorporeal pumping as a life-saving measure following massive infarction are two other aspects of the coronary problem that are likely to interest this Association for many more years.

The badly damaged heart will require support for days rather than for hours. In the Circulation and Surgical Research Laboratories at the Boston City Hospital we have been working on a veno-arterial pumping system without an oxygenator that we believe will be capable of providing such long-term support.

Blood is drained by gravity from the superior vena cava and pumped into a femoral artery. The coronary and cerebral systems are supplied by fully oxygenated blood from the lung. Superior caval blood, draining from the upper half of the body, is still 50 to 60 per cent saturated with oxygen. The lower extremities and splanchnic organs are able to function on this moderately reduced blood while relatively inactive. The pump is pneumatically operated with Hufnagel type ball-valves at each end, and is exceptionally gentle with blood elements.

It has been possible to pump as much as 70 c.c./Kg./min. with this equipment. In this slide, the lightly stippled columns are control cardiac outputs, the cross-hatched sections heart output during bypass, and the solid areas the bypass flow. The slide shows that the volumes pumped amount to about one half the body requirement. The output of the heart is reduced by approximately the volume pumped.

This slide shows the effect of veno-arterial pumping on aortic pressures. Pumping raises the diastolic pressure, a factor that should favor better flow through the heart muscle itself while the volume component of heart work is reduced.

We have been able to pump 50 to 60 c.c./Kg./min. *continuously for as long as 54 hours with survival and only transient*, minor effects on the clotting mechanism, acid-base balance, and electrolyte pattern. We believe the hemodynamic effects of such veno-arterial pumping for a period of days will prove to be beneficial following major infarction of heart muscle.

DR. DONALD MULDER, Los Angeles, Calif.—Since Dec. 1, 1957, Dr. William Longmire and Dr. Jack Cannon of the UCLA Surgical Department have operated upon 5 patients for severe incapacitating angina pectoris. Previous studies of Blumgart and Schlessinger, Gregg, Thornton and Mautz, as well as numerous autopsy observations have led us to believe that localized occlusion of the major coronary arteries with a patent distal arterial tree occurred frequently in the patient with angina pectoris without evidence of myocardial infarction or generalized atherosclerosis. In an especially devised exercise test, none of these patients could exercise for more than 3½ minutes without typical pain and the electrocardiographic changes of myocardial ischemia.

At operation one or more, usually two, of the major coronary arteries were found to be almost completely occluded. A technique of endarterectomy was perfected in the dog and found readily applicable in the human being. In the 5 cases mentioned, the obstructing plug was removed from both the right main and the left anterior descending coronaries in 2 patients. In all cases, the smaller distal branches were patent by inspection, palpation, and by demonstration of adequate "back bleeding" once the obstructing core was removed from the artery and its major branches. The technique is as follows.

The results of this procedure have been quite encouraging. Although the second patient was lost from asystole after the removal of the core from the second major coronary vessel, the other 4 patients have all survived. They have been entirely free from angina for the relatively short period since surgery. Exercise tolerance has been greatly improved in all patients and the ECG tracings do not show evidence of myocardial ischemia. We believe further evaluation of the technique is indicated as the early experiences are most promising.

SIR RUSSELL C. BROCK, London, England.—Although I have had the privilege of visiting the United States on many occasions, I am ashamed to say this is the first time I have been able to attend a meeting of The American Association for Thoracic Surgery. It is a particular source of pleasure to me to be present on this occasion and to pay tribute to Dr. Graham. I do not wish to add to the eulogy so ably presented by Dr. Burford this morning, but I would like to say that I feel this tribute very deeply because I had the privilege of being one of Dr. Graham's "boys," having worked with him in 1930-31. One thing that was mentioned, and very rightly so, was the great friendship that Dr. Graham encouraged between England and this country through the plan of inviting trainees here. And that brings up another point I would like to mention. Sir, I was very happy to see you wearing the chain of office which was presented last year by the Association of Thoracic Surgeons of Great Britain and Ireland to this Association as a bond of friendship between the two Associations. I am happy to see also that not only does the badge of office grace the President, but that the President graces the badge.

I should like to take as my theme the fact that Dr. Claude Beck has presented his observations based on a quarter of a century of work. The whole world looks to the United States for its achievements with regard to coronary artery disease. As you know, O'Shaughnessey of London in the early 1930's did some basic work on cardio-omentopexy, but since that time the greater part of the work has emanated from the North American continent. I was at first rather reluctant to speak on this subject because on a recent occasion I made some comments which Dr. Beck misunderstood but I am glad to have the opportunity to clarify my remarks. I have been reluctant until recently to embark upon these various surgical procedures for the improvement of coronary artery disease because, quite frankly, I have been unimpressed with the results of the attempts to bring a new blood supply to the heart from outside. I would say that the position is justified. Dr. Beck's own conclusion as a result of his work is that the heart seems to resist the bringing of a blood supply from the outside. I am much impressed with Dr. Beck's presentation, not of the ability to bring a new blood supply from the exterior, but of the redistribution of coronary blood flow within the myocardium by increase in intercoronary anastomoses. This seems to me to be a logical and accepable result of the various stimulating factors caused by the Beck procedure and can well explain the good clinical results obtained.

That the simple act of opening the pericardium and examining the heart manually can be followed by quite profound reaction and disturbances is well known to all of us and reaches its most notable form in the so-called ''post-valvotomy'' syndrome, which is really a ''postpericardial insult'' syndrome and can follow simple needle puncture of the heart. It ordinarily has nothing to do with recurrence of rheumatic activity.

The effects of a cardiotomy are well known to any cardiac surgeon who has reoperated on the heart within a year of the first operation. The myocardium is soft, often discolored, and the patient's reaction to the interference may be unduly severe. It seems as if the heart easily suffers a notable traumatic myocarditis and to me it is easy to understand how such a process results in a great increase of intercoronary anastomoses.

When I say that I am unconvinced that a new and effective blood supply can be brought to the heart from outside, I do not mean that I am criticizing adversely the many splendid attempts to revascularize the heart from a systemic source. I merely state that so far I am not convinced that they succeed in the way they claim to succeed, although they may bring benefit by some other mechanism. I just do not want, today, to become involved in a critical discussion of these various procedures. I applaud the spirit and purpose which guides them and hope that they will achieve success.

DR. BECK (Closing).—There are two approaches for effective treatment. One involves addition of blood to the heart. On the basis of a large experience, the statement is made that the heart resists the addition of blood from outside sources. Many years ago my associates and I grafted tissues on the heart including the internal mammary artery with the expectation that blood would go across the graft to the heart. Later on, the specimens were injected with a watery dye and routinely it was possible to inject from the heart into the graft and from the graft into the heart. But, when we used a thicker material consisting of a solution of barium sulfate and gelatin, it was only the occasional specimen that showed blood vessels large enough to carry blood. Several specimens injected with this material entered the internal mammary artery which was grafted on the heart (for specimens see Mautz and Beck, J. THORACIC SURG. 7: 113, 1937, and Beck, Ann. Surg. 118: 792, 1943). I have also seen specimens in Dr. Vineberg's laboratory in which channels large enough to carry blood were present. But, in the laboratory, we and others have had indifferent success in demonstrating such vessels. Perhaps we did not do our experiments right. We have also added blood into the venous system, directing it to the capillaries in a retrograde direction. This worked well for awhile but later on intimal thickening cut off this inflow, but this operation gave the heart an excellent set of intercoronaries and, indeed, the greatest degree of protection was provided by this operation.

Early in our work (1932) the idea of cleaning out coronary arteries was considered and applied first in autopsy specimens and later on at the operating table after the death of the patient. The possibility of yield seemed to be small. This idea is being revived and is being tried on patients even though surgeons have not been successful in arteries of this size elsewhere in the body. The widespread involvement of the coronary tree by the disease, often including secondary branches of coronary arteries in a large percentage of cases, the possibility of changing stenosis into occlusion by the surgical manipulation, and the possibility of creating an imbalance and electrocuting currents are considerations that will determine success or failure of this manipulation. Dr. John Madden of New York told me of his success in cleaning out the descending artery but at autopsy the right and circumflex arteries were severely stenosed. It is possible that this created an imbalance, oxygen differentials, and electrocuting currents.

I am grateful to Sir Russell Brock for his discussion; I appreciate it. He emphasizes distribution of the heart's own blood as one method of attack in treatment. I am pleased that he accepts this as a possibility for effective treatment. I had the privilege to attend the Harvey Tercentenary Congress in London last year. I shall never forget this meeting. In grace, dignity, and historical significance, this meeting could not be duplicated anywhere else in the world except in London and for William Harvey. The physicians of Britain have warm affection for The American Association for Thoracic Surgery. They showed it last year when the President of their Association, Mr. George Mason, presented to our President, Dr. Cameron Haight, a medallion to establish the Chain of Command to be passed on from President to President for all time into the future.

THE CLINICAL SIGNIFICANCE OF COR PULMONALE IN THE REDUCTION OF CARDIOPULMONARY RESERVE FOLLOWING EXTENSIVE PULMONARY RESECTION

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SINCE the first successful one-stage pneumonectomy was performed over 25 years ago there has been great interest in the alterations of respiratory and circulatory function following the extensive loss of lung tissue.

Longacre[1, 2, 3] and his associates in experimental studies on dogs observed the effects of pneumonectomy upon pulmonary and cardiocirculatory functions in young growing and adult animals. In puppies subjected to pneumonectomy, enlargement of the remaining lung and histologic evidence of pulmonary hyperplasia were reported. The capacity of these animals to perform exhausting exercise was comparable to normal control animals. Similar studies on adult animals revealed findings of emphysematous change in the remaining lung in the form of fragmentation of alveoli and loss of elastic tissue. These animals showed marked physiologic deficiencies under conditions of physical stress.

Subsequently, clinical studies of the effects of pneumonectomy in children were reported. In a study of 4 young children followed up to adult life, Lester, Cournand, and associates[4, 5] observed that 2 of the patients, in spite of a moderate degree of pulmonary distention, showed a reduction in breathing reserve from normal and a marked degree of oxygen unsaturation in the arterial blood during strenuous exercise. The other 2 patients showed improved adaptation and good physiologic performance. A study of 10 children by Peters and associates[6] revealed that in spite of increases in size of the remaining lung with high residual volumes in one half of the cases, the physiologic responses of these patients to exercise were within the range of normal.

Observations on adults following pneumonectomy have also been reported. Cournand and Berry,[7] in a study of 12 patients before and after pneumonectomy, found the chief difference between postpneumonectomy patients and normal subjects was the reduction in breathing reserve in various states of activity. This reduction was caused by a decrease in maximum breathing

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capacity and was greater in the older patients. It was their impression that "the late effects of pneumonectomy upon gas exchange in the lungs, the state of respiratory gases in the arterial blood and the cardiocirculatory function were insignificant." In a later study on the pulmonary circulation and alveolar ventilation perfusion relationships after pneumonectomy, Cournand and co-workers[8] demonstrated that in 9 patients studied late after pneumonectomy there was an increase in the size of the remaining lung, a reduction of maximum breathing capacity, an approximately normal arterial oxygen saturation at rest and slightly below normal during exercise, the average pulmonary blood flow and mean pulmonary arterial pressure were within the normal range at rest and that a mild pulmonary hypertension inevitably developed in the course of mild exercise. Pulmonary function studies of Birath[9] and Burnett[10] and their associates produced findings similar to those of Cournand.

It has been recognized for some time that in certain individuals, notably those in the older age group, extensive pulmonary resection (pneumonectomy) with an immediate reduction of cardiorespiratory reserve results in cor pulmonale, right heart failure, and death.[11, 12] However, more recently interest has been aroused by a group of postpneumonectomy patients who were able to adjust to the immediate effects of pneumonectomy and resume their work and activities without disability, only years later to begin to experience progressive dyspnea on exertion resulting in a marked reduction of their functional capacity and sometimes forcing the individual into a state of retirement and semiinvalidism. The "late" effects experienced by these individuals were not always well correlated with abnormalities in their pulmonary function studies. Occasionally, such a patient would present the findings of right heart failure. Therefore, the mechanism of cor pulmonale resulting from a reduction of pulmonary parenchyma came under consideration. In view of the widespread use today of pneumonectomy as the operation of choice for carcinoma of the lung, as well as the frequent performance of extensive bilateral pulmonary resection, these "late" results should become of ever increasing importance.

In an attempt to understand better the mechanisms involved in the "late" results of extensive pulmonary resection and to elucidate further the role of pulmonary hypertension in such cases, physiologic studies were performed on a series of patients at various intervals following pneumonectomy and bilateral resection.

MATERIAL FOR STUDY

Physical characteristics and clinical data concerning the 29 patients studied are tabulated in Table I. There were 6 females and 23 males ranging in age from 23 to 74 years.

Pneumonectomy had been performed in 25 of the 29 cases, in 19 cases for a diagnosis of primary carcinoma of the lung, in 2 cases for tuberculosis, in 2 cases for cystic disease of the lung, in 1 case for chronic suppurative disease, and in 1 case for a bronchial adenoma. Two of the pneumonectomy patients

TABLE I. PHYSICAL CHARACTERISTICS, DIAGNOSIS, AND FUNCTIONAL CAPACITY OF PATIENTS FOLLOWING EXTENSIVE PULMONARY RESECTION

	PATIENT	AGE	SEX	SURFACE AREA M.^{2}	TYPE OF SURGERY	DIAGNOSIS	YEARS AFTER SURGERY	FUNCTIONAL CLASS
1	E. B.	44	F	1.73	Right pneumonectomy	Tuberculosis	3	II
2	B. B.	52	F	1.56	Left lower lobectomy, lingulectomy, and right middle lobectomy	Lipoid pneumonia	2	II
3	H. Be.	23	M	1.84	Left pneumonectomy	Cystic disease	5	I
4	H. Bo.	69	M	1.87	Left pneumonectomy	Carcinoma	3	IV
5	P. C.	69	M	1.49	Left pneumonectomy	Carcinoma	12	II
6	E. C.	42	M	1.88	Right pneumonectomy	Carcinoma	6	II
7	S. D.	65	M	1.84	Left pneumonectomy	Carcinoma	9	I
8	B. F. (1)	42	F	1.53	Right pneumonectomy	Bronchial adenoma	5	II
9	B. F. (2)	45	F	1.58	Right pneumonectomy	Bronchial adenoma	7½	II
10	J. G.	39	F	1.67	Right middle and lower lobectomies; left lower lobectomy and lingulectomy	Bronchiectasis	11	I
11	M. H.	68	M	1.90	Left upper lobectomy	Carcinoma	2	III
12	E. J.	49	M	1.62	Right pneumonectomy	Carcinoma	7	I
13	J. K.	37	F	1.77	Left pneumonectomy	Tuberculosis	3	I
14	E. K.	45	M	2.04	Right pneumonectomy	Carcinoma	6	II
15	A. L. (1)	46	M		Left pneumonectomy	Carcinoma	1 mo.	III
16	A. L. (2)	47	M		Left pneumonectomy	Carcinoma	1½	III
17	O. L.	54	M	1.79	Right pneumonectomy	Carcinoma	11	III
18	H. M. (1)	47	M	1.78	Right pneumonectomy	Carcinoma	3	I
19	H. M. (2)	49	M	1.64	Right pneumonectomy	Carcinoma	5	I
20	J. M.	57	M	1.90	Right pneumonectomy	Carcinoma	½	III
21	A. M.	53	M	1.64	Left pneumonectomy	Carcinoma	1	III
22	R. N.	72	M	2.00	Left pneumonectomy	Carcinoma	12	II
23	M. O.	63	M	1.84	Right pneumonectomy	Cystic disease, infected	3	II
24	L. R. (1)	61	M	1.71	Right pneumonectomy and thoracoplasty	Carcinoma	14	II
25	L. R. (2)	63	M	1.74	Right pneumonectomy and thoracoplasty	Carcinoma	15½	III
26	W. R.	58	M	1.74	Right pneumonectomy	Lung abscess	3½	I
27	E. S.	30	M	1.80	Left lower lobectomy and lingulectomy; right lower lobectomy	Bronchiectasis	11	I
28	J. So.	65	M	2.08	Right pneumonectomy	Carcinoma	3	II
29	J. Sz.	74	M	1.97	Left pneumonectomy	Carcinoma	7½	IV
30	H. T.	69	F		Right pneumonectomy	Carcinoma	3 wks.	IV
31	J. T.	64	M	1.59	Right pneumonectomy	Carcinoma	3½	II
32	W. W.	52	M	2.08	Right pneumonectomy	Carcinoma	3	II
33	P. W.	57	M	1.80	Left pneumonectomy	Carcinoma	7½	I

had also had a supplemental thoracoplasty performed on the side of the pneumonectomy Four of these patients were studied on two occasions with an intervening period of 1½ to 2½ years

Three patients had undergone bilateral pulmonary resection—2 for bilateral bronchiectasis and 1 for bilateral lipoid pneumonia One patient had undergone only a left upper lobectomy for a primary carcinoma of the lung

The studies were performed from 3 weeks to 15½ years after the surgical procedures

Initially, investigations were made on patients who presented themselves with complaints of progressive dyspnea on exertion and consequent reduction of work and exercise capacity Later, as interest in this problem was stimulated the study was extended to include other patients who, after a comparable type of surgery, were entirely asymptomatic or offered only minor complaints Their findings were compared with those in the group of symptomatic patients The distribution of the patients as to age and type of surgery performed is summarized in Table II

TABLE II 33 PATIENTS
AGE OF PATIENTS—PROCEDURE PERFORMED

	20 29 YEARS	30 39 YEARS	40 49 YEARS	50 59 YEARS	60 69 YEARS	70 79 YEARS
Left pneumonectomy (11)	1	1	2	2	3	2
Right pneumonectomy (18)	0	0	8	4	6	0
Bilateral lobar resections (4)	0	2	0	1	1*	0

*Left upper lobe only

METHOD OF STUDY

The patient undergoing investigation was hospitalized for 36 to 48 hours During this hospitalization a complete clinical history and physical examination were obtained, electrocardiogram chest roentgenogram, pulmonary function studies, and cardiac catheterization studies were performed The clinical evaluation of the individual was carefully standardized by the use of a detailed questionnaire and clinical evaluation sheet

The patient's functional capacity was graded on a scale of I to IV Class I included those patients having no limitation of physical activity and in whom ordinary physical activity caused no discomfort, Class II signified a slight to moderate limitation of physical activity, Class III included those with a moderate to great limitation of physical activity, while Class IV was assigned to the patients unable to carry on any physical activity without discomfort

Pulmonary function studies were carried out in the pulmonary physiology laboratory and included spirometric determination of ventilatory capacity, residual volume, nitrogen washout curves, ear oximetry and, in a few subjects pulmonary diffusing capacity Residual volumes were determined by a modification of the Darling method[13]

Cardiac catheterization was employed to measure right heart pressures and cardiac output at rest and during moderate exercise [illegible] catheterization was not technically possible in all cases, and [illegible] ventricular pressures were obtained in those cases. Arterial oxygen saturation was continuously recorded during the cardiac catheterization by a Wood earpiece and recording oximeter.[14] Right heart pressure measurements were made by means of a Statham strain gauge manometer and a Grass amplifier-recording instrument. Cardiac output was determined by the direct Fick method on 12 of the patients in a resting state and during the last minute of a 3-minute exercise period. Simultaneous mixed venous and systemic arterial blood samples were analyzed for oxygen content by the Van Slyke method.[15]

A 3-minute period of moderate exercise was required of each patient in the supine position by bicycling against resistance or flexing each leg against a 5-pound resistance.

RESULTS

The functional capacity of each patient at the time of study as determined by the history and clinical evaluation is tabulated in Table I. There appeared to be a rough correlation between the age of the patient at the time of the study and his functional capacity. However, a more striking relationship was found between the age of the patient at the time of his surgery and his resultant functional class (Table III); the older the patient at the time of surgery, the more likely he was to experience a reduction of functional capacity later.

TABLE III. RELATIONSHIP OF PATIENT'S AGE AT SURGERY AND RESULTANT FUNCTIONAL CLASS

FUNCTIONAL CLASS	10-19	20-29	30-39	40-49	50-59	60-69
	(AGE IN YEARS)					
I (11 patients)	2	1	1	4	3	0
II (12 patients)	0	0	4	2	2	4
III (7 patients)	0	0	0	4	2	1
IV (3 patients)	0	0	0	0	0	3

This was especially true of the group over the age of 60 at the time of surgery; in our series none of these patients was functionally unimpaired, and all 3 of our Group IV patients fell into this age group. There were no striking differences between the functional capacities of the right and left pneumonectomy groups, but the patients having undergone extensive bilateral resections presented little or no functional incapacity (Table IV). No relationship was demonstrated between the length of survival since pulmonary resection and the resulting functional capacity of the individual.

TABLE IV. 33 PATIENTS
PROCEDURE PERFORMED—FUNCTIONAL CAPACITY

	I	II	III	IV
Left pneumonectomy (11)	4	2	3	2
Right pneumonectomy (18)	4	10	3	1
Bilateral lobar resections (4)	2	1	1*	0

*Left upper lobe only.

TABLE V. PULMONARY FUNCTION STUDIES OF PATIENTS FOLLOWING EXTENSIVE PULMONARY RESECTION

CASE NO.		FUNCTIONAL CLASS	T.L.C. (L.)	V.C. (L.)	R.V. (L.)	$\frac{R.V.}{T.L.C.} \times 100$ (%)	MMF (L./SEC.)	MBC (L./MIN.)	1 SECOND V.C.	N₂ WASHOUT CURVE
Left Pneumonectomy										
3	H. Bc.	I	5.2	3.95 (91%)	1.25	24	2.4	110 (82%)	71%	normal
7	S. D.	I		2.40 (72%)			1.1	69 (72%)	76%	normal
13	J. K.	I	3.85	2.05 (68%)	1.5	39	1.5	57 (60%)	74%	normal
33	P. W.	I	3.9	2.0 (57%)	1.9	49	1.5	63 (62%)	78%	normal
5	P. C.	II	3.2	1.8 (59%)	1.3	41	1.2	30 (40%)	69%	normal
22	R. N.	II	4.2	2.2 (63%)	2.0	48	0.56	30 (30%)	54%	abnormal
21	A. M.	III	3.4	1.6 (47%)	1.65	49	0.92	35 (37%)	70%	normal
4	H. Bo.	IV	3.8	1.05 (31%)	2.4	63	0.57	*	74%	slightly abnormal
29	J. Sz.	IV	5.66	2.5 (75%)	3.03	54	0.55	32 (43%)	46%	abnormal
Right Pneumonectomy										
12	E. J.	I	3.2	2.2 ([illegible])	1.0	32	2.4	59 (61%)	89%	normal
18	H. M. (1)	I	3.5	2.15 ([illegible])	1.35	38	0.79	54 (49%)	69%	normal
19	H. M. (2)	I	3.9	1.6 ([illegible])	2.1	54	0.6	31 (31%)	63%	normal
26	W. R.	I	3.08	1.6 ([illegible])	1.35	44	2.2	53 (57%)	98%	normal
1	E. B.	II	2.4	1.5 ([illegible])	0.9	37	0.53	36 (33%)	62%	normal
6	E. C.	II	3.6	2.3 ([illegible])	1.3	36	1.7	54 (44%)	81%	normal
8	B. F. (1)	II		1.70 ([illegible])				49 (55%)	85%	normal
9	B. F. (2)	II	3.2	1.8 ([illegible])	1.4	44	1.6	31 (39%)	70%	normal
14	E. K.	II	3.8	2.6 ([illegible])	1.2	32	1.6	63 (49%)	77%	normal
23	M. O.	II	4.1	2.1 ([illegible])	1.85	45	1.7	76 (79%)	80%	normal
21	L. R. (1)	II		1.03 ([illegible])			0.71	21 (23%)	79%	normal
28	J. So.	II	3.55	2.0 ([illegible])	1.45	41	3.0	50 (46%)	88%	normal
31	J. T.	II	3.75	1.55 ([illegible])	2.2	59	1.2	33 (39%)	78%	abnormal
32	W. W.	II	3.8	2.5 ([illegible])	1.3	34	1.7	65 (52%)	70%	normal
17	O. L.	III		0.97 ([illegible])			0.5	13 (12.5%)	50%	abnormal
20	J. M.	III	3.15	1.7 ([illegible])	1.35	43	1.5	56 (52%)	89%	normal
25	L. R. (2)	III	2.8	1.2 ([illegible])	1.6	57	0.52	31 (34%)	71%	normal
Bilateral Resections										
10	J. G.	I	4.0	2.0 (68%)	2.0	50	0.75	25 (28%)	58%	slightly abnormal
	E. S.	I	5.1	3.5 (88%)	1.6	31	2.5	103 (79%)	77%	normal
	B. B	II		1.18 (58%)				23 (32%)	67%	
Left Upper Lobectomy										
[illegible]	M. H.	III	4.3	1.9 (56%)	2.4	56	1.5	54 (57%)	82%	normal

*Unable to perform test

T.L.C. = total lung capacity; V.C. = vital capacity; R.V. = residual volume; MMF = maximum midexpiratory flow; MBC = maximum breathing capacity; 1 sec. V.C. = per cent of vital capacity expired in first second; N₂ Washout Curve = nitrogen washout curve.

The results of the pulmonary function studies and cardiac catheterization studies are tabulated in Tables V and VI and are represented graphically in Figs. 1 and 2. The average results will be discussed separately for each functional class.

Table VI. Circulatory Studies of Patients Following Extensive Pulmonary Resection

CASE NO.	FUNCTIONAL CLASS	RIGHT HEART SYSTOLIC PRESSURE (MM. HG)		ARTERIAL OXYGEN SATURATION (%)		OXYGEN CONSUMPTION (ML./MIN.)		CARDIAC OUTPUT (L./MIN.)		CARDIAC INDEX (L./MIN./M.^{2})	
		REST	EXER.	REST	EXER.	REST	EXER.	REST	EXER.	REST	EXER.
1 E. B.	II	22	39	98	95.5	218	542	6.25	8.26	3.61	4.78
2 B. B.	II	28									
4 H. Bo.	IV	34	56	93	86	218	271	3.91	3.30	2.09	1.76
5 P. C.	II	33	48	96	93						
6 E. C.	II	35	70								
7 S. D.	I	34	66	92	87						
8 B. F. (1)	II	25		96	97						
9 B. F. (2)	II	34	43	97	97	212	434	5.06	5.52	3.20	3.49
10 J. G.	I	17	38	95	93						
11 M. H.	III	23	48	86							
12 E. J.	I	30	40	97	90						
13 J. K.	I	25	41	95	97	235	579	5.5	9.3	3.11	5.25
14 E. K.	II	21	43	97	99						
15 A. L. (1)	III	31	43	93	93						
16 A. L. (2)	III	30	70								
17 O. L.	III	56	85	90	86						
18 H. M. (1)	I	28	39	97.5	95						
19 H. M. (2)	I	19	34	95	94	198	680	4.01	9.03	2.44	5.5
20 J. M.	III	28	31	96	95		661		7.7		4.05
21 A. M.	III	25	39	96	94	266	448	6.2	6.9	3.78	4.20
23 M. O.	II	22	34	96	95	189	685	4.76	8.73	2.59	4.75
24 L. R. (1)	II	35	84	94	85						
25 L. R. (2)	III	38	56	94	95	206	591	3.2	6.3	1.84	3.62
26 W. R.	I	33	42	97.5	95.5						
27 E. S.	I	25	39	97	95.5						
28 J. So.	II	33		98	98	318		3.6		1.73	
29 J. Sz.	IV	75	112	96	90						
30 H. T.	IV	35	52								
31 J. T.	II	48	65	97	95	198	410	3.5	4.7	2.2	2.96
32 W. W.	II	35	55								
33 P. W.	I	41	75	96.5	95	296	727	4.75	10.25	2.64	5.69

Class I.—

Considered as a group the ten studies performed on 9 patients an average of 6.5 years postoperatively showed the following average findings:

1. Total lung capacity, 3.97 L.
2. Vital capacity, 64.7 per cent of the normal predicted for a patient with two lungs.
3. Residual volume, 1.56 L.
4. Maximum breathing capacity, 58.1 per cent of the predicted value for a normal chest with both lungs.
5. First second vital capacity, 75.3 per cent.
6. Maximum midexpiratory flow, 1.57 L./sec.

7. Pulmonary artery systolic pressure: rest 28 mm. Hg.; exercise 46 mm. Hg.
8. Arterial oxygen saturation: rest 96 per cent, exercise 94 per cent.

Class II.—

The average findings of the group of 13 studies on 12 patients, an average 6.2 years postoperatively, were as follows:

1. Total lung capacity, 3.56 L
2. Vital capacity, 57 per cent of the normal predicted for a patient with two lungs
3. Residual volume, 1.47 L.

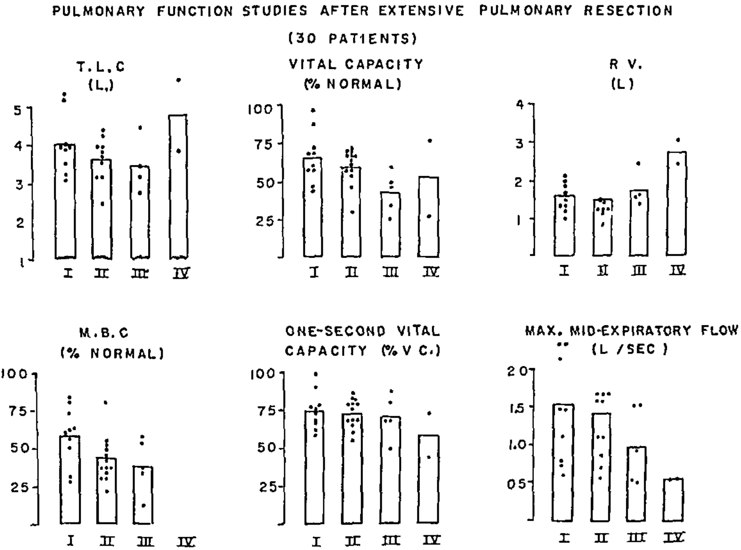


Fig 1—Results of pulmonary function studies grouped according to the patient's functional class Bars represent average values for each group Dots represent results of individual studies in each group T L C (L) = total lung capacity in liters, Vital Capacity (% Normal) = per cent of vital capacity predicted for a normal subject with two lungs, R V. (L) = residual volume in liters, M B C (% Normal) = per cent of the predicted maximum breathing capacity of a normal chest with both lungs One-Second Vital Capacity (% V.C) = per cent of the vital capacity expired in the first second, Max Mid-Expiratory Flow (L /Sec) = maximum midexpiratory flow in liters per second (16), I, II, III, IV = the functional class of the patients in each group (See text for definition)

4. Maximum breathing capacity, 44 per cent of the predicted value for a normal chest with both lungs
5. First second vital capacity, 74 per cent.
6. Maximum midexpiratory flow, 1.44 L./sec.
7. Pulmonary artery systolic pressure: rest 31 mm. Hg; exercise 53 mm. Hg.

8. Arterial oxygen saturation: rest 96 per cent; exercise 94.5 per cent.

Class III.—

The average findings of the group of 7 studies on 6 patients, an average of 4.5 years postoperatively, were as follows:

1. Total lung capacity, 3.41 L.
2. Vital capacity, 42 per cent of the normal predicted for a patient with two lungs.
3. Residual volume, 1.75 L.
4. Maximum breathing capacity, 38.5 per cent of the predicted value for a normal chest with two lungs.
5. First second vital capacity, 72.4 per cent.
6. Maximum midexpiratory flow, 0.988 L./sec.

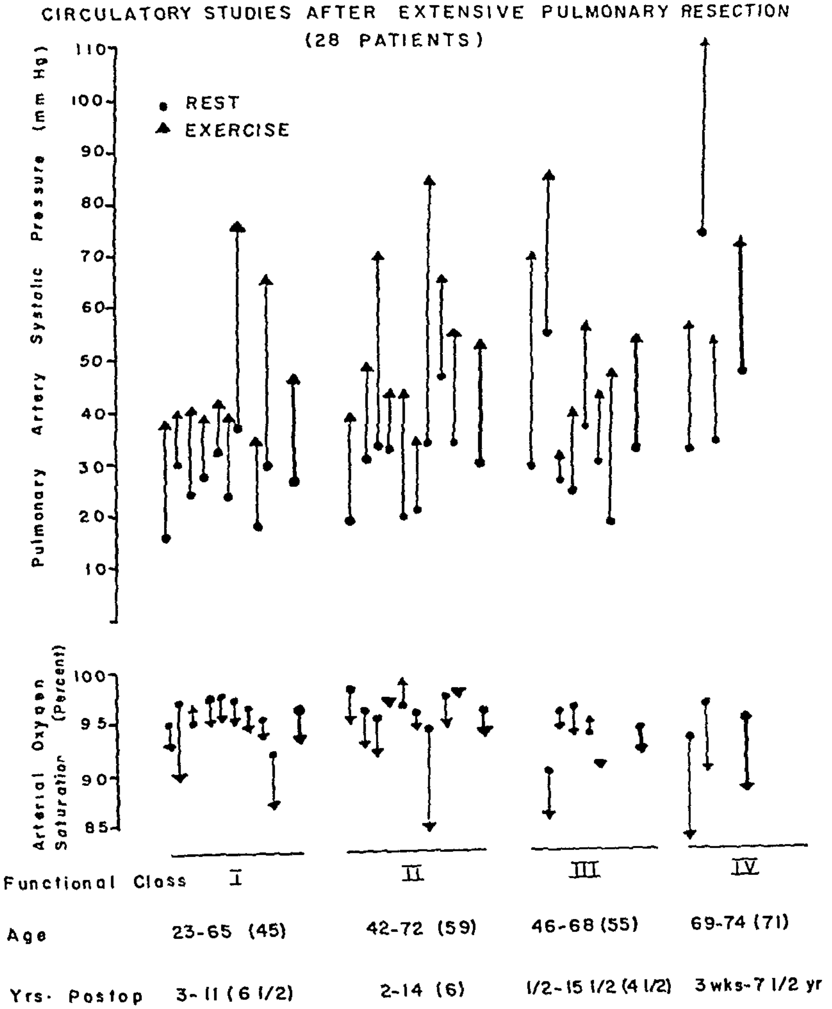


Fig. 2.—Pulmonary artery pressures and arterial oxygen saturations during rest and exercise, grouped according to the patient's functional class.

The lighter vertical lines represent the changes during exercise *for each subject;* the heavier vertical lines at the extreme right of each group represent the averages for the groups; Functional Class—(see text for definition); Age = the range of ages of patients within each group and the average age for the group; Yrs. Postop. = the range *of the number of years* after surgery for the patients in each group and the average for the group.

7. Pulmonary artery systolic pressure: rest 33 mm. Hg; exercise 53 mm. Hg.
8. Arterial oxygen saturation: rest 94 per cent; exercise 92 per cent.

Class IV.—

The average findings of the group of 3 patients studied an average of 5.25 years postoperatively were as follows:

1. Total lung capacity, 4.73 L.
2. Vital capacity, 53 per cent of the normal predicted for a patient with two lungs.

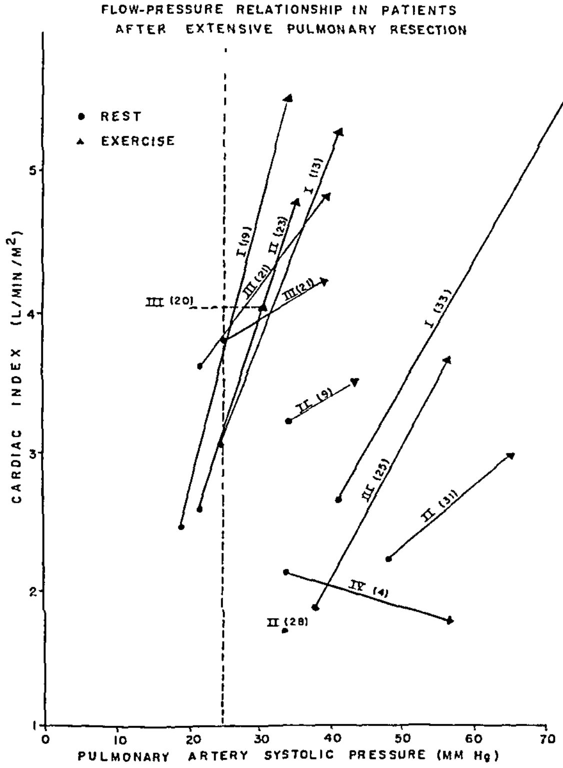


Fig. 3.—Relationship of pulmonary artery pressure to pulmonary blood flow during rest and exercise.

Each line represents the change during exercise for 1 patient; dots represent single determinations at rest or during exercise; numbers in parentheses identify patients by case number (see Table I); roman numerals signify the functional class of each case; vertical dotted line represents the pulmonary artery pressure level in normal subjects at rest and during exercise.

3. Residual volume, 2.71 L.
4. Maximum breathing capacity (obtained in only 1 case).
5. First second vital capacity, 60 per cent.
6. Maximum midexpiratory flow, 0.560 L./sec.
7. Pulmonary artery systolic pressure: rest 48 mm. Hg; exercise 73 mm. Hg.
8. Arterial oxygen saturation: rest 94.5 per cent; exercise 88 per cent.

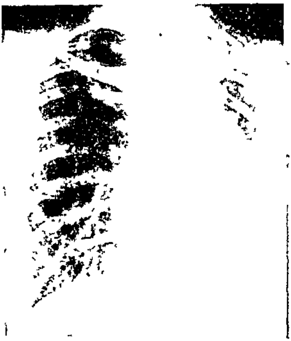
A graphic representation of the relationship of the pulmonary blood flow to the pulmonary artery pressure in the 12 patients studied is presented in Fig. 3 and will be discussed later.

DISCUSSION

The results of the pulmonary function studies on this group of patients form the basis of a subsequent report and will not be considered fully here. However, in considering the relationship between the findings of the pulmonary function studies and the patients' functional capacities, as illustrated in Fig. 1, a number of generalizations were drawn. There appeared to be a correlation between the functional capacity and abnormalities in the maximum breathing capacity, residual volume, and maximum midexpiratory flow.[16] In the patients with increasing amounts of functional impairment, the maximum breathing capacity and maximum midexpiratory flow values became progressively more reduced, while, in these same patients, the residual volume became greater. This observation would support the impression that in these patients there were emphysematous changes in the remaining lung as represented by marked overdistention, increased airway resistance, as well as arterial oxygen unsaturation and abnormalities in the alveolar gas mixing (abnormal nitrogen washout curves). It should be pointed out that although a patient may have presented the picture of a markedly overdistended lung with marked herniation to the opposite side on x-ray studies, this did not necessarily represent emphysematous changes in that lung; other portions of the study revealed relatively normal findings and the patient experienced little or no functional disability. Patient 13 (J. K., Fig. 4) represents such a case.

Considering the pulmonary artery pressures with regard to the functional capacity of the patient, it was found that in Class I, 5 of the 8 patients displayed normal pulmonary artery pressures at rest but experienced increases from 25 to 120 per cent over resting levels during the exercise period. The remaining 3 patients in Class I had resting pulmonary artery pressures elevated 16 to 64 per cent above normal resting levels, and these levels during exercise increased 27 to 94 per cent above the resting levels. Five of the 12 patients in functional Class II had normal resting pulmonary artery pressure; during exercise these pressures rose 55 to 105 per cent above the resting levels. The 7 remaining patients in Class II presented right heart pressures elevated 32 to 52 per cent above normal resting values. During exercise, these pressures became further elevated to levels 35 to 140 per cent above the *elevated resting* levels. In the Class III group of cases, 3 of the 7 patients had normal resting pulmonary artery pressures that increased 18 to 110 per cent above this level during the exercise period. The other 4 Class III patients at rest had pulmonary artery pressures elevated 16.5 to 125 per cent above normal. While exercising, these patients produced 39 to 133 per cent increases in pressure. All 3 of the Class IV patients displayed elevated resting right heart pressures; in 2 cases 40 per cent above the normal resting value and in the third case the elevation during rest was 200 per cent higher than normal. During the exercise period these pressures increased 48.5 to 65 per cent above the elevated resting values.

Pneumonectomy, as well as extensive bilateral pulmonary resection, results in a marked reduction of the total pulmonary capillary bed. Normally only a portion of the total capillary bed of the lung functions at one time. During exercise, with an increase in the amount of oxygen uptake in the lungs associated with increases in cardiac output, undoubtedly a greater fraction of the total lung capillary bed functions, as indicated by the lack of alteration in right heart pressure and arterial oxygen saturation in the normal individual.



FUNCTIONAL CLASS I.

T.L.C.	3.85 L.
V.C.	2.05 L. (68%)
R.V.	1.5 L.
M.B.C.	57.0 L./min. (60%)
1 sec V.C.	74%

	Rest	Exer.
Pulm. Art. Press.	$\frac{25}{8}$ (14)	$\frac{41}{17}$ (25)
Art. O_2 Sat.	95%	97%
Pulse Rate	110.0	146.0
O_2 Consumption	,235.0	579.0
Cardiac Output (L./min.)	5.5	9.3

Fig. 4.—A roentgenogram of Patient 13 (J. K.), a 37-year-old woman, taken 3 years post-pneumonectomy (left).

T.L.C. = total lung capacity· V.C. = vital capacity—per cent of normal predicted for subject with two lungs; R.V. = residual volume; M.B.C. = maximum breathing capacity—per cent of predicted value for a normal chest with both lungs; 1 sec. V.C. = per cent of the vital capacity expired in the first second; Pulm. Art. Press = pulmonary artery pressures (mm. Hg) (mean pulmonary artery pressure in parentheses); Art. O_2 Sat. = arterial oxygen saturation; O_2 Consumption = oxygen consumption (ml./min.).

In the patient who has undergone pneumonectomy, the blood flow through the remaining lung is doubled. If the total capillary bed of the remaining lung does not change and the functioning capillary bed increases, then the reserve or nonfunctioning capillary bed of that lung is decreased. Consequently, when the oxygen requirements of the body are increased, such as by exercise, and the pulmonary blood flow increases, the reserve capillary bed may no longer be adequate to accommodate these demands. This would then result in an elevation of the right heart pressure and possibly a concomitant fall in arterial oxygen saturation.

The effect of the increased blood flow through the remaining capillary bed over the course of years is a matter for speculation and is under investigation. Possibly the increased flow leads to alterations in these vessels, which in turn reduces the capillary bed and, in turn, the "reserve" capillary bed. However, the progressive reduction of the reserve capillary bed may be unrelated to the increase in blood flow and be related to pathologic processes occurring in the lung tissue with a secondary effect on the capillary bed, such as in emphysema. Undoubtedly, both or either process may play a role in an individual patient, as will be illustrated in later discussion.

It has been observed in normal subjects that the mean pulmonary arterial blood pressure did not change as the pulmonary blood flow increased up to 10 L./M.^{2} body surface area during a steady state of severe exercise.[17] Cournand[8] reported that in 5 subjects after pneumonectomy the mean pulmonary arterial pressure remained within normal limits with a pulmonary blood flow of less than 5 L./M.^{2} body surface area; the mean pulmonary arterial pressure rising progressively as the blood flow increased beyond this level.

FUNCTIONAL CLASS II.

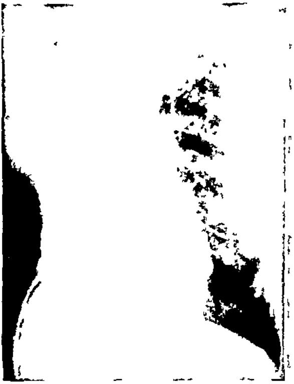
T.L.C.	2.4 L.	
V.C.	1.5 L. (54%)	
R.V.	0.9 L.	
M.B.C.	36.0 L./min.(33%)	
1 sec V.C.	62%	
	Rest	Exer.
Pulm. Art. Press.	$\frac{22}{8}$(13)	$\frac{39}{15}$(23)
Art. O_2 Sat.	98%	95.5%
Pulse Rate	92.0	112.0
O_2 Consumption	218.0	542.0
Cardiac Output (L./min.)	6.25	8.26

Fig. 5.—A roentgenogram of Patient 1 (E. B.), a 44-year-old woman, taken 8 years post-thoracoplasty (right) and 4 years postpneumonectomy (right). Same key as in Fig. 4.

In contrast to the findings of Cournand, the results were somewhat different in the group of patients in which the relationship of pulmonary blood flow to pulmonary artery pressure was determined (Fig. 3).

In 5 cases, No. 1 (E. B.; Fig. 5), No. 9 (B. F.), No. 21 (A. M.), No. 25 (L. R; Fig. 6), No. 31 (J. T.), despite the fact the pulmonary blood flow was less than 5 L./M.^{2} per minute, the pulmonary artery pressure increased. This suggested that the distensibility curve of the pulmonary vascular bed of these remaining lungs differed from that of normal lungs; i.e., a limitation in the expansibility of the vascular bed by a reduction in the number of small vessels, and/or a decrease in the cross-section of the lumen of the arterioles and precapillaries.

Three patients in our series, No. 17 (O. L.), No. 4 (H. Bo.), and No. 29 (J. Sz.), functional Classes III, IV, IV, respectively, demonstrated abnormalities in their pulmonary function studies indicating emphysema in the remaining lung. All of these patients had elevated resting pulmonary artery pressures that increased markedly during mild to moderate exercise. One patient, No. 17 (O. L.), since the time of the study, has become a Class IV patient. Another patient, No. 4 (H. Bo.), has died since the study, presenting a clinical picture of progressive dyspnea and right heart failure in addition to metastatic disease.

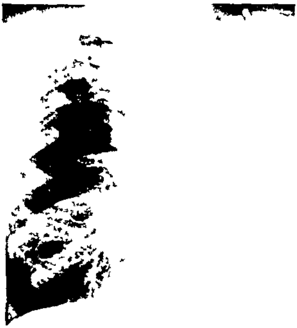


FUNCTIONAL CLASS III.

T.L.C.	2.8 L.
V.C.	1.2 L. (34%)
R.V.	1.6 L.
M.B.C.	31.0 L./min.(34%)
1 sec V.C.	71%

	Rest	Exer.
Pulm.Art.Press.	$\frac{38}{13}$(21)	$\frac{56}{30}$(39)
Art.O_2 Sat.	94%	95%
Pulse Rate	88.0	116.0
O_2 Consumption	206.0	591.0
Cardiac Output (L./min.)	3.2	6.3

Fig 6—A roentgenogram of Patient 25 (L R), a 63-year-old man, taken 15½ years post-pneumonectomy (right) and post-thoracoplasty (right). Same key as in Fig 4



FUNCTIONAL CLASS IV.

T.L.C.	5.66 L.
V.C.	2.5 L. (75%)
R.V.	3.03 L.
M.B.C.	32.0 L./min.(43%)
1 sec V.C.	46%

	Rest	Exer.
Pulm.Art.Press.	$\frac{75}{35}$(48)	$\frac{112}{45}$(67)
Art. O_2 Sat.	96%	90%
Pulse Rate	84.0	92.0

Fig 7.—A roentgenogram of Patient 29 (J S), a 74-year-old man taken 7½ years post-pneumonectomy (left) Same key as in Fig. 4.

The third patient, No. 29 (J. Sz; Fig. 7), was nearly a complete respiratory cripple, experiencing marked dyspnea at rest. All 3 of these patients following pneumonectomy resumed relatively normal activity and only later [illegible] experience the onset of progressive dyspnea leading to functional [illegible] The question of whether the emphysema process [illegible] in th[illegible] prior to surgery, or whether pneumonectomy [illegible] in remaining lung brought about the emphysema, cannot be answered from this study. Unfortunately preoperative pulmonary function studies of these patients were not available.

Two of the Class I patients, No. 7 (S. D.) and No. 33 (P. W.), were found to have markedly elevated pulmonary artery pressures at rest and during exercise. Pulmonary function studies in these 2 cases failed to reveal any striking abnormalities. Patient No. 33 (P. W.) was found to have a pulmonary blood flow during exercise of 5.69 L./M.^{2} per minute which may explain much of the increased pressure during exercise, but fails to explain the elevated resting pulmonary artery pressure with a blood flow of 2.64 L./M.^{2} per minute. One may speculate on the future of Patients No. 7 (S. D.) and No. 33 (P. W.). Will the pulmonary hypertension produce changes in the pulmonary vessels resulting in even more marked elevations of pulmonary artery pressures, or will future pulmonary function studies reveal a pathologic process in the lung parenchyma with the pulmonary hypertension representing the first manifestation of such a process?

Patient No. 24, 25 (L. R.) represented one of the few instances in which repeat studies have been performed on the same person after first observing pulmonary hypertension. The first 10 to 11 years after his pneumonectomy, this patient carried on almost unrestricted activity. Progressive dyspnea developed and in the 1½-year interval between studies he moved from Class II to Class III in spite of no significant differences in the pulmonary function studies or cardiac catheterization findings. In retrospect it is possible that this patient should have been classified as Class III in the first study, but due to the fact that he had a stoic personality, was assigned to Class II.

Patient No. 20 (J.M.), a Class III patient, represented the opposite type of problem. On the basis of pulmonary function studies and cardiac catheterization findings, it might be predicted that he should be in Class I. However, this patient was extremely apprehensive and was reluctant to exert himself physically, 6 months after pneumonectomy. Since the time of his investigation he has shown remarkable improvement in his functional capacity.

In comparing the findings in the group of patients who had undergone bilateral resection with those of the postpneumonectomy patients, it is not possible to conclude whether the removal of a comparable volume of lung tissue bilaterally is better tolerated than a pneumonectomy. The bilateral resection group studied is too small and involves younger individuals than the majority of the postpneumonectomy patients. Nevertheless, the possibility exists that some of the adverse effects observed after pneumonectomy could be attributed to the deviation of mediastinal structures and thereby to the impairment of ventilatory and cardiocirculatory function. Mediastinal shift was absent in the group of patients following extensive bilateral resection.

SUMMARY AND CONCLUSION

1. Physiologic studies were performed on 29 patients 3 weeks to 15½ years following pneumonectomy or extensive bilateral pulmonary resection.

2 Results of the studies were compared with the functional capacity of each individual

3 The older the patient at the time he underwent pneumonectomy, the more likely he was to experience a reduction of functional capacity later

4 Reduction of functional capacity correlated well with reduction of maximum breathing capacity and maximum midexpiratory flow, and correlated inversely with the increase in residual volume

5 Comparison of the functional capacity with pulmonary artery pressures at rest and during moderate exercise suggested a direct relationship As the functional incapacity increased, the levels of pulmonary artery pressure at rest and during exercise were found more elevated

6 Reduction of functional capacity appeared to be more closely related to the effects of pulmonary hypertension than alterations in arterial oxygen saturation

7 Pulmonary artery pressure–pulmonary blood flow relationships in the remaining lung after pneumonectomy differed from that of a normal lung and suggested a limitation in the expansibility of the vascular bed

8 Mechanisms of development of pulmonary hypertension as a late result of pneumonectomy are suggested

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(For Discussion, see page 379)

EFFECT OF SEVERE UNILATERAL HYPOXIA ON THE PARTITION OF PULMONARY BLOOD FLOW IN MAN

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When a moderate degree of hypoxia is induced in either animal or human subjects an elevation of the pulmonary arterial pressure frequently occurs. This pressor response appears to be caused by pulmonary vasoconstriction, since the left atrial pressure is not altered and since the cardiac output is only moderately increased.[1, 9]

Such observations led von Euler and Liljestrand[9] to suggest that local hypoxia might play a role in controlling the distribution of the pulmonary blood flow. They reasoned that a local reduction in the alveolar oxygen tension would constrict the vessels in the affected area, thereby diverting a portion of the blood carried by these channels through vessels in better aerated parts of the lungs. Several investigators have tested this hypothesis by inducing unilateral hypoxia. Although it has been shown that this stimulus can change the partition of the pulmonary blood flow in animals,[10, 1] there has been conflicting evidence that this response can be elicited in man.[17, 1]

In a previous series of experiments in this laboratory, the administration of 10 per cent oxygen to one lung in 6 human subjects had no observable effect on the partition of the pulmonary blood flow.[18] The present study was undertaken to investigate the effects of more severe hypoxia. In this study, 5 per cent oxygen was administered to one lung.

METHOD

The details of the method used to measure the blood flow through each lung have been described previously.[18] In brief, the technique combined right heart catheterization, bronchospirometry, and arterial cannulation. The simultaneous use of these three devices made it possible to measure (1) the gas exchange in each lung separately, (2) the concentration of oxygen in the arterial and mixed venous blood, and (3) the pressures in the pulmonary and brachial arteries.

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*Fellow of the Nuffield Foundation.

TABLE I. EFFECT OF UNILATERAL HYPOXIA ON GAS EXCHANGE AND BLOOD GAS COMPOSITION*

SUBJECT	STATE	$\dot{V}_{E_H}$ (L./MIN.)	$\dot{V}_{E_L}$ (L./MIN.)	$\dot{V}_{E_T}$ (L./MIN.)	$\dot{V}_{O_{2H}}$ (ML./MIN.)	$\dot{V}_{O_{2L}}$ (ML./MIN.)	$\dot{V}_{O_{2T}}$ (ML./MIN.)	$\dot{V}_{CO_{2H}}$ (ML./MIN.)	$\dot{V}_{CO_{2L}}$ (ML./MIN.)	$\dot{V}_{CO_{2T}}$ (ML./MIN.)	R_{E_H}	R_{E_L}	R_{E_T}	CAP_{O_2} (ML./100 ML.)	Ca_{O_2} (ML./100 ML.)	(Ca_{O_2} minus $C\bar{v}_{O_2}$) (ML./100 ML.)
Group I. Patients With Minimal Unilateral Lung Disease																
B. M.	Control	4.65	5.12	9.77	123	100	223	75	81	156	.61	.81	.70	17.5	16.3	3.8
	Hypoxic	5.11	6.00	11.11	212	17	229	84	77	161	.40	4.5	.70	17.1	15.6	2.6
A. M.	Control	5.14	4.22	9.36	147	80	227	120	77	197	.82	.96	.87	14.2	13.1	3.5
	Hypoxic	5.62	4.72	10.34	231	−7	224	125	65	190	.54	−9.3	.85	14.2	12.0	3.8
D. H.	Control	5.66	5.54	11.20	171	82	253	121	100	221	.71	1.22	.87	17.8	16.8	3.1
	Hypoxic	7.30	6.34	13.64	294	1	295	174	82	256	.59	82.0	.87	17.8	16.5	3.1
	Control	6.51	5.74	12.25	210	76	286	144	96	240	.69	1.26	.84	17.8	16.6	3.2
S. L.	Control	5.71	5.03	10.74	153	104	257	95	81	176	.62	.78	.68	19.4	18.8	3.4
	Hypoxic	4.98	4.63	9.61	227	1	228	96	70	166	.42	70.0	.73	19.4	16.4	3.0
	Control	5.23	4.61	9.84	135	106	241	103	80	183	.76	.75	.76	19.4	17.9	3.1
J. Mc.	Control	5.21	6.44	11.65	129	166	295	95	128	223	.74	.77	.76	18.2	16.8	2.9
	Hypoxic	6.00	8.02	14.02	272	21	293	115	140	255	.42	6.7	.87	18.2	12.6	3.0
	Control	5.00	6.30	11.30	141	173	314	100	134	234	.71	.77	.75	18.2	16.3	3.6
Group II. Patients With Lobectomy and "Denervated" Lung																
P. H.	Control	4.15	4.75	8.90	159	117	276	94	102	196	.59	.87	.71	19.1	18.1	3.5
	Hypoxic	5.70	5.70	11.40	270	10	280	127	86	213	.47	8.6	.76	18.6	15.6	3.8
	Control	4.52	4.73	9.25	150	96	246	90	85	175	.60	.89	.71	18.5	16.9	4.0
R. J.	Control	5.80	5.36	11.16	154	120	274	133	120	253	.86	1.0	.92	20.0	19.1	5.1
	Hypoxic	4.66	4.72	9.38	248	13	261	121	81	202	.49	6.2	.77	20.1	17.0	4.1
	Control	5.50	5.38	10.88	181	117	298	122	111	233	.67	.95	.78	19.8	18.9	5.4

*The symbols used in Tables I, II, and III are defined as follows[23]: $\dot{V}_E$, volume of gas expired per minute (BTPS); $\dot{V}_{O_2}$, volume of oxygen taken up per minute (STPD); $\dot{V}_{CO_2}$, volume of carbon dioxide expired per minute (STPD); R_E, respiratory exchange ratio; CAP_{O_2}, arterial blood oxygen capacity; Ca_{O_2}, arterial blood oxygen content; $C\bar{v}_{O_2}$, mixed venous blood oxygen content; Sa_{O_2}, arterial blood oxyhemoglobin saturation; $\dot{Q}$, rate of volumetric blood flow.

The sub-subscripts H, L, and T refer to the high oxygen lung, the low oxygen lung, and both lungs, respectively.

The protocol consisted of three consecutive breathing periods In the first, the lung free of disease breathed 25 per cent oxygen while the opposite lung breathed 21 per cent oxygen Pressures were recorded at 3 minute intervals, and at the tenth and fifteenth minutes, samples of blood and gas were collected for the calculations of flow

During the second period, unilateral hypoxia was induced by substituting 5 per cent oxygen for the 21 per cent oxygen mixture Pressures were recorded every 3 minutes, and the arterial blood oxyhemoglobin saturation was measured every 4 The blood and gas samples used to measure flow were collected at the fifteenth and twenty-fifth minutes of hypoxia

The third period was completed in five of the seven studies During this period, 21 per cent oxygen was substituted for the 5 per cent oxygen mixture so that *final control measurements could be obtained* Pressures were recorded at 3 minute intervals, and at the fifteenth minute the last collections of blood and gas were made

CALCULATIONS

The total pulmonary blood flow was calculated by applying the Fick principle This entailed dividing the total oxygen uptake by the arteriovenous oxygen difference The flow through the lung breathing the high oxygen mixture was estimated by the same principle, but here it was assumed (1) that the saturation of the blood leaving this lung was 98 per cent, and (2) that its content of oxygen was equal to that calculated from the expression shown below[18] [20]

$$0\,98\ (O_2\ \text{Capacity} -0\,5) +0\,3$$

Finally, the flow through the opposite lung was estimated by subtracting the flow through the high oxygen lung from the total pulmonary flow

SUBJECTS

Two groups of subjects were studied The first included 5 men believed to have normal pulmonary vessels one (A M) had recovered from pneumonia, one (D H) had shown complete resolution of a lung abscess, and 3 had been admitted to the hospital for treatment of a minimal tuberculous focus at the apex of one lung

The second group was composed of 2 men who had each undergone a modified right upper lobectomy for bronchogenic carcinoma approximately 14 months prior to the time of the study In the course of the surgery, the proximal end of the divided right main stem bronchus had been anastomosed to the distal end of the intermediate bronchus, and all of the adjacent tissues, including the nerves, had been divided The pulmonary artery had also been stripped of adventitia and the adjacent nerves sectioned Hence, only a nerve supply lying near the inferior pulmonary vein could have remained intact It was believed, therefore that the right middle and lower lobes were almost completely denervated

RESULTS

The results are presented in Tables I, II, and III.

In Tables I and II, the initial control values represent an average of two successive measurements. In Table III, the partition of the ventilation and blood flow in the individual control measurements is shown. The measurements made after 15 minutes of unilateral hypoxia are not recorded in the tables since, in several instances, this period proved to be too brief for the attainment of a steady state of the gas exchange.

TABLE II. EFFECT OF UNILATERAL HYPOXIA ON ARTERIAL BLOOD OXYHEMOGLOBIN SATURATION, PARTITION OF TOTAL PULMONARY BLOOD FLOW, AND PULMONARY ARTERIAL PRESSURE

SUBJECT	STATE	S_{aO_2} (%)	$\dot{Q}_H$ (L./MIN.)	$\dot{Q}_L$ (L./MIN.)	$\dot{Q}_T$ (L./MIN.)	$\frac{\dot{Q}_L}{\dot{Q}_T}100$ (%)	PULMONARY ARTERIAL PRESSURE (MM. HG)		
							S.	D.	M.
			Group I. Patients With Minimal Unilateral Lung Disease						
B. M.	Control	96	2.73	3.14	5.87	53	23*	4*	
	Hypoxic	92	5.89	2.92	8.81	33	23*	4*	
A. M.	Control	96	3.59	2.90	6.49	45	20	9	15
	Hypoxic	87	4.20	1.69	5.89	29	22	11	16
D. H.	Control	96	4.75	3.41	8.16	42			
	Hypoxic	94	7.54	1.98	9.52	21			
	Control	95	5.38	3.56	8.94	40			
S. L.	Control	99	4.50	3.06	7.56	41	16	8	11
	Hypoxic	86	4.20	3.40	7.60	45	16	8	11
	Control	94	3.38	4.39	7.77	56	16	8	11
J. Mc.	Control	95	3.49	6.68	10.17	66	25	11	15
	Hypoxic	70	3.40	6.37	9.77	65	37	14	22
	Control	91	2.88	5.84	8.72	67	29	13	17
			Group II. Patients With Lobectomy and "Denervated" Lung						
P. H.	Control	97	4.18	3.71	7.89	47	27	10	16
	Hypoxic	85	4.35	3.02	7.37	41	35	14	20
	Control	93	3.00	3.15	6.15	51	25	9	15
R. J.	Control	97	2.85	2.52	5.37	47	28	16	21
	Hypoxic	86	3.76	2.61	6.37	41	34	19	25
	Control	97	3.17	2.35	5.52	43	28	16	21

*Pressures recorded from right ventricle.

In general, the values of ventilation and cardiac output measured during the control periods were larger than those usually found in resting subjects. These large values, which were also observed in the previous study,[18] were partly attributable to the presence of the bronchospirometry catheter, and partly to the dose of atropine given to suppress bronchial secretions. The values measured after 25 minutes of hypoxia were also large but satisfied the steady-state criteria.[5] In each of the subjects, both the total oxygen uptake and the respiratory quotient measured at the end of 25 minutes were comparable to those measured before hypoxia was induced.

In 3 of the subjects in the first group (A. M., D. H., and B. M.) unilateral hypoxia reduced the fraction of the total blood flow perfusing the hypoxic lung. The sequence of events in Subject A. M. is illustrated in Fig. 1. It

TABLE III. PARTITION OF VENTILATION AND BLOOD FLOW BETWEEN THE TWO LUNGS DURING THE CONTROL AND HYPOXIC PERIODS

SUBJECT	STATE	TIME OF EXPOSURE (MIN.)	$\frac{\dot{V}_{E_L}}{\dot{V}_{E_T}} \times 100$ (%)	$\frac{\dot{Q}_L}{\dot{Q}_T} \times 100$ (%)
Group I. Patients With Minimal Unilateral Lung Disease				
B. M.	Control	8	52	49
	Control	12	53	56
	Hypoxic	26	54	33
A. M.	Control	12	44	44
	Control	16	46	45
	Hypoxic	27	46	29
D. H.	Control	11	49	42
	Hypoxic	26	46	21
	Control	17	47	40
S. L.	Control	17	47	41
	Hypoxic	25	48	45
	Control	12	47	56
J. Mc.	Control	10	56	66
	Control	16	55	66
	Hypoxic	28	57	65
	Control	12	56	67
Group II. Patients With Lobectomy and "Denervated" Lung				
P. H.	Control	12	53	46
	Control	16	53	47
	Hypoxic	26	50	41
	Control	16	51	51
R. J.	Control	13	48	47
	Control	20	48	48
	Hypoxic	30	50	41
	Control	14	49	43

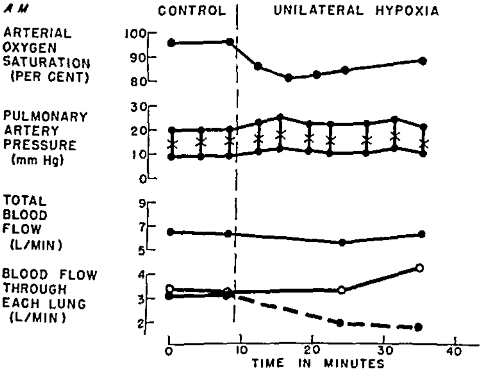

Fig. 1.—Effect of inducing severe unilateral hypoxia in Subject A. M. In the bottom graph, open circles and solid line indicate blood flow through the lung breathing the high oxygen mixture; closed circles and dashed line indicate blood flow through the hypoxic lung.

can be seen that the induction of hypoxia produced a prompt fall in the arterial oxyhemoglobin saturation. By the fifth minute of hypoxia, the saturation had reached its lowest level, after which it began to rise. At the end of 15 minutes, a change in the partition of flow was apparent, and at the end of the twenty-fifth minute, this change was quite pronounced. The sequence of events in Subject D. H. was similar, but that in Subject B. M. was somewhat different and is shown in Fig. 2. From the figure it can be seen that no shift in flow was evident at the fifteenth minute of hypoxia, but a shift appeared after 25 minutes had elapsed.

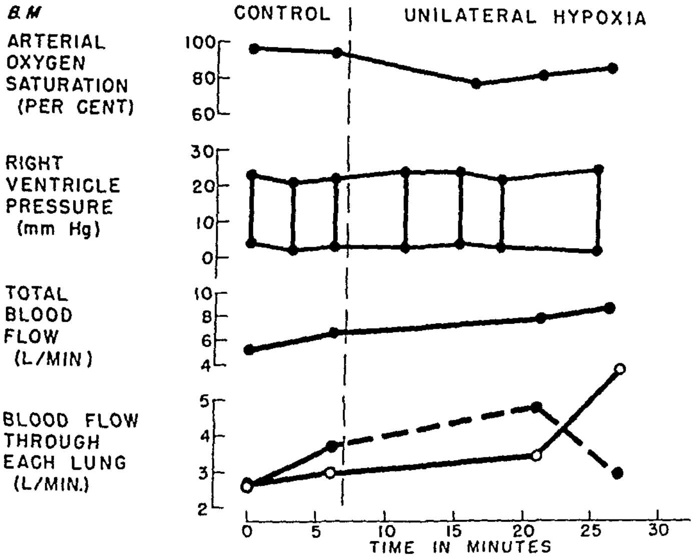

Fig. 2.—Effect of inducing severe unilateral hypoxia in Subject B. M. In the bottom graph, open circles and solid line indicate blood flow through the lung breathing the high oxygen mixture; closed circles and dashed line indicate blood flow through the hypoxic lung.

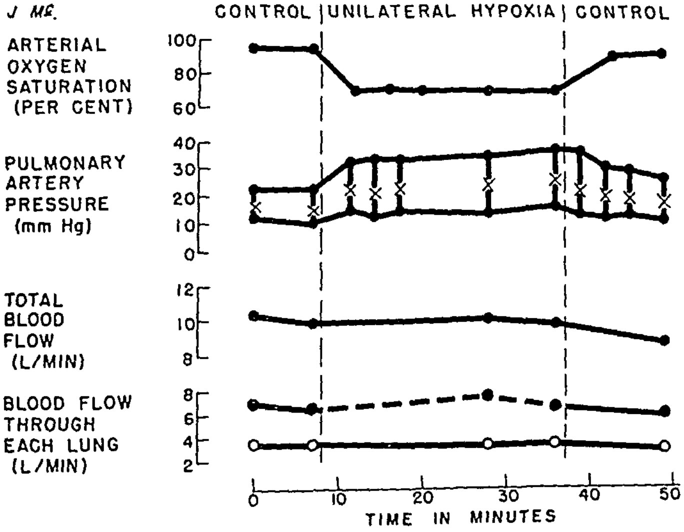

Fig. 3.—Effect of inducing severe unilateral hypoxia in Subject J. Mc. In the bottom graph, open circles and solid line indicate blood flow through the lung breathing the high oxygen mixture; closed circles and dashed line indicate blood flow through the hypoxic lung.

The results in Subject S. L. were inconclusive. After 25 minutes of hypoxia, the partition of flow was the same as it had been during the initial control period. However, the final control measurement indicated that the lung which had been hypoxic was carrying an increased fraction of the total pulmonary flow.

The response of Subject J. Mc. is illustrated in Fig. 3. Following the induction of unilateral hypoxia, the arterial oxyhemoglobin saturation fell to 70 per cent and remained at this low level. At the same time, pulmonary hypertension developed, but the partition of flow between the lungs remained identical to that during the control periods.

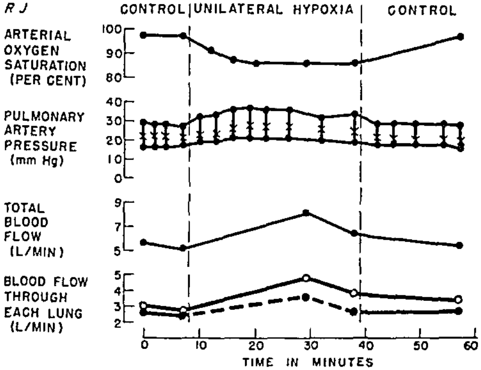

Fig. 4.—Effect of inducing severe unilateral hypoxia in Subject R. J. who had a denervated lung. In the bottom graph, open circles and solid line indicate blood flow through the lung breathing the high oxygen mixture; closed circles and dashed line indicate blood flow through the hypoxic lung.

In the 2 subjects in the second group, the denervated lung breathed the 5 per cent oxygen mixture. During hypoxia, the fraction of the total flow perfusing this lung was somewhat diminished, while the pressure in the pulmonary artery definitely rose (Fig. 4).

DISCUSSION

Four points merit emphasis: (A) the limitations of the method, (B) the demonstration that unilateral hypoxia may affect the partition of the pulmonary blood flow, (C) the degree of hypoxia necessary to produce an effect on the pulmonary vessels, and (D) the mechanism whereby the effect of hypoxia is mediated.

A. *The Limitations of the Method.*—The reliability of the calculated values of blood flow through the individual lungs rests directly on the validity of the assumption that the oxygen content of the blood leaving the high oxygen lung can be estimated. The reasons for believing that the assumption is valid have been considered in two previous reports.[18, 20] In brief, these reasons are (1) that in each case the lung receiving the 25 per cent oxygen mixture was normal, (2) that on a previous day the administration of 25 per cent oxygen to both lungs had produced an arterial blood oxyhemoglobin saturation of at least 98 per cent, (3) that in the lung breathing the high oxygen mixture, the calculated $P_{A_{O_2}}$ was approximately 120 mm. Hg, and (4) that in the initial control period, with the bronchospirometry catheter in place, the arterial oxyhemoglobin saturation was never lower than 95 per cent. It would seem, therefore, that the expression used to calculate content would closely estimate the concentration of oxygen in the blood leaving the high oxygen lung.

A second limitation of the method stems from the fact that when the two lungs breathe gas mixtures containing different concentrations of nitrogen, a difference exists between the tension of nitrogen in the mixed venous blood and that in the alveolar air. This difference persists regardless of the length of time allowed for the attainment of a steady state. Thus, in the lung breathing the lower concentration of nitrogen, the volume of this gas expired exceeds that inspired, while in the opposite lung the reverse situation obtains. This inequality must necessarily affect the calculation of oxygen uptake. But theoretical considerations indicate that the effect of this phenomenon introduces an error of the order of only 1 per cent.

B. *The Demonstration That Unilateral Hypoxia May Affect the Partition of the Pulmonary Blood Flow.*—From Table III it is apparent that the fractions of flow perfusing the low oxygen lung showed close agreement in the two measurements made in the initial control period. Hence, the changes in this figure produced by unilateral hypoxia in 3 of the subjects suggest that a shift in flow away from the hypoxic lung actually occurred. In general, these changes were smaller and less constant than those observed by Blakemore, Carlens, and Björkman[19] in patients with lung disease. These investigators also used a technique involving bronchospirometry, cardiac catheterization, and arterial cannulation. However, their method of calculation of partition of blood flow involved (1) equilibration of the gas in the hypoxic lung with the mixed venous blood, and (2) estimation of the arterial blood oxygen tension when a high concentration of oxygen (80 per cent) was breathed. From the published data, it is not possible to determine whether a steady state of the respiration and circulation was attained.

In our own studies, it was of interest that although the partition of ventilation between the two lungs was not affected by unilateral hypoxia, the fraction of the total carbon dioxide eliminated by the hypoxic lung was reduced. Rahn and Bahnson[14] previously reported a difference in the alveolar carbon dioxide tensions in the two lungs of dogs subjected to unilateral hypoxia. They suggested that the difference might either be due to the Bohr effect, or to the fact that unilateral vasoconstriction altered the ventilation-perfusion relationships in the lungs.

Of particular interest was the fact that unilateral hypoxia produced a change in the partition of carbon dioxide excretion in the 2 patients with denervated lungs, even though in these patients it was questionable whether a shift in flow occurred.

C. *The Degree of Hypoxia Necessary to Produce an Effect on the Pulmonary Vessels.—Several investigators have demonstrated that the inhalation* of 12 per cent oxygen by both lungs almost always elicits a pressor response in the pulmonary artery. Presumably, this response is caused by constriction of the pulmonary vascular bed. One might expect, therefore, that the administration of 10 per cent oxygen to one lung would cause unilateral pulmonary vasoconstriction. The fact that it did not[18] may be attributable to the conditions under which gas is exchanged in the hypoxic lung.

The following considerations deal with this question. They are based on the fact that the alveolar oxygen tension can be roughly calculated by first dividing the alveolar carbon dioxide tension by the respiratory quotient, and then by subtracting this number from the tension of oxygen in the trachea. If we assume that the barometric pressure is 760 mm. Hg, then the tracheal oxygen tension when both lungs breathe 12 per cent oxygen is 86 mm. Hg. If we further assume an alveolar carbon dioxide tension of 40 mm. Hg and a respiratory quotient of 0.80, then the alveolar oxygen tension is approximately 36 mm. Hg in both lungs.

When 10 per cent oxygen is breathed, the tension in the trachea is 71 mm. Hg. When this mixture is breathed by *a single lung, the lung continues to* expire carbon dioxide although the rate of oxygen uptake substantially falls. As a consequence, the respiratory quotient has been found to be consistently greater than 1.0. If we assume a value of 1.3, which was the average of the values measured in the previous study,[18] and if we again assume an alveolar carbon dioxide tension of 40 mm. Hg, then the alveolar oxygen tension in the hypoxic lung is approximately 41 mm. Hg. In short, when 10 per cent oxygen is inspired unilaterally, the alveolar oxygen tension in the hypoxic lung is higher than it would be if 12 per cent oxygen were being breathed by both lungs.

Similar calculations made with the data in Table I indicate that the administration of 5 per cent oxygen to one lung reduces the oxygen tension to below 35 mm. Hg. Hence, a very low concentration of inspired oxygen is needed in order to produce an effect in one lung comparable with that produced when 12 per cent oxygen is breathed by both.

D. *The Mechanism Whereby the Effect of Hypoxia Is Mediated.*—In earlier studies in this laboratory, the inhalation of 12 per cent oxygen by both lungs elicited a pressor response in the pulmonary artery in each of 2 patients who had undergone sympathectomy.[8, 21] The first patient had had bilateral resection of the cervical and upper four dorsal sympathetic ganglia; the second had had all of the sympathetic ganglia removed. The results in these 2 patients confirm those made earlier in animals,[2] namely, that the sympathetic ganglia are not essential for the mediation of the hypoxic effect. In the present series, the results obtained in the patients with a denervated lung, although not conclusive, seem to support the concept that the effects of local hypoxia are not mediated through the sympathetic nerves.

Beyond showing that nerves may not be important in the mediation of the response, our data shed no light on the exact mechanism involved. The observations made in J. Mc., the normal subject, who developed pulmonary hypertension without a shift in flow, suggest that two mechanisms may be present. On the one hand, the shift in flow may be caused by pulmonary hypoxia, as a result of a local action not yet clarified. On the other, the rise in the pulmonary arterial pressure would seem to indicate that both lungs were affected; a response which may be related somehow to the oxygen tension in the blood.[22]

SUMMARY

The administration of 5 per cent oxygen to one lung in 5 normal subjects reduced the fraction of the total flow perfusing the hypoxic lung in 3. In the fourth, the results were inconclusive, and, in the fifth pulmonary hypertension developed with no change in the partition of flow.

In 2 subjects in whom most of the nerves to one lung had been sectioned, unilateral hypoxia raised the pulmonary arterial pressure and produced a questionable shift in flow.

It appears that unilateral hypoxia can affect the partition of the blood flow between the lungs in human subjects. However, this effect is not invariably present and is seen only when the concentration of oxygen in the inspired gas mixture is very low.

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DISCUSSION

(PAPERS BY ADAMS [PAGE 352] AND HIMMELSTEIN [PAGE 369] AND THEIR ASSOCIATES)

DR ANDRE COURNAND, New York, N Y—I am greatly honored to have been invited to participate in the program this morning I have not come to the podium to present a paper but, indeed, to pay my tribute to the memory of Dr Evarts Graham My associate and close collaborator for more than 17 years, Dr Himmelstein, will present our paper This is due him since the data to be reported and discussed were secured to a great extent because of his skill and his thorough knowledge of the several techniques used in combination

My first encounter with Dr Graham dates back to 1937, on the occasion of the meeting of this Association held at Saranac Lake On the program there were four papers dealing with the application of physiological tests to problems of thoracic surgery If I recall correctly, our own presentation met with little enthusiasm, probably not so much because the subject was novel, but because of the accent of the speaker! During the meeting I had been impressed by the admirably controlled and self possessed appearance of one of the members of the Association When he came to tell me that he was much interested in the content of my paper, I felt somewhat less distressed by the apparent lack of enthusiasm of the audience Several years later, Dr Graham repeated this kindly gesture when, in collaboration with Dr Frank Berry, I presented at one of our meetings the results of our studies in patients before and after pneumonectomy His remarks can be found in the discussion published in the JOURNAL OF THORACIC SURGERY

On a third occasion, Dr Graham gave me an even precious evidence of his sympathy In a way this was probably an feeling toward Frenchmen whom he had learned to like W had written him a letter of recommendation on behalf of Dr. Andre Germain, a Fellow of the French Cultural Service, who was sent to the United States to be trained as a thoracic surgeon. Within a week not only had I received a favorable answer but my protégé was starting to work as an assistant resident on the world-renowned surgical service at Barnes Hospital. This was a great privilege and opportunity for him. For me, the exchange of letters, and the rapid and favorable decision, was proof that Dr. Graham, like other great men, was not bound by precedents or by conformity to strict rules.

DR. PAUL NEMIR, JR., Philadelphia, Pa.—I wish to congratulate Dr. Adams and his associates on this excellent presentation. Studies such as these are important and will, I think, contribute equally as much in our efforts to improve long-term survival statistics as will the significant studies relating to blood vessel and lymph node invasion, and the studies reported by Dr. Meade.

Dr. Meade stated that in 32 per cent of the autopsies studied there was no evidence of recurrence. Undoubtedly a large number of the failures to survive for appreciable periods of time was due to the fact that pulmonary insufficiency occurred following the resectional therapy. This has certainly been true in an analysis of our own series of cases.

If it were possible by more accurate preoperative pulmonary function studies to delineate and exclude this group of patients, then we could expect better survival rates following resection.

While it is true that withholding operation from the patient with precarious pulmonary function is not going to prolong his survival, at least he will be spared the distressing situation of being a pulmonary cripple.

We have continued our studies of pulmonary function, utilizing the method of unilateral pulmonary artery occlusion reported before the Association 2 years ago. Our findings are in agreement with those reported by Dr. Adams. An elevated resting pulmonary artery pressure or a sustained increment following balloon occlusion of the unilateral pulmonary artery has been almost uniformly of grave prognostic significance.

We have found that small increments of the order of 6 to 8 mm. Hg following occlusion are of great significance. Since the average age of the patients we have studied has been 61 years, the control resting pulmonary artery pressures have been at the very upper limits of normal. Small increments could therefore be reasonably expected to have greater significance. I would like to ask Dr. Adams the magnitude of the elevations they have noted.

A second measurement which we have found to be important is the wedge pressure. Elevations of this pressure may also be correlated with a poor prognosis.

While it is true that these detailed studies may not be routinely performed, the knowledge we are gaining from them will allow for more accurate preoperative evaluation of the patient undergoing pulmonary resection, and I am sure that more simple methods for obtaining similar information will soon be available.

DR. WILLIAM S. BLAKEMORE, Philadelphia, Pa.—It is a fitting tribute to Dr. Graham to have a presentation of physiologic studies in this morning's program. One of Dr. Graham's earliest contributions was in the field of pulmonary physiology. The work which Dr. Himmelstein has presented is especially significant in corroborating the findings in man that were previously shown in animals. Several years ago Dr. Björkman, Dr. Carlens, and I performed similar studies in man, with one lung rebreathing a mixture of about 6 to 7 per cent oxygen and 5 per cent carbon dioxide and the other lung rebreathing a mixture of 50 to 80 per cent oxygen and less than 0.3 per cent carbon dioxide. We found that differences in oxygen and/or carbon dioxide concentrations in the inspired gas had an effect upon pulmonary blood flow. Our method differed from the method used by these investigators and we were disappointed that Fishman and this group did not find a change using 10 per cent oxygen in the hypoxic lung, since the method used in these studies should provide greater accuracy Now, however, they have today reported changes in blood flow with lower than 10 per cent oxygen in the hypoxic lung Since even these methods of calculating the blood flow through each lung are likely to have a high per cent of error, additional studies using more direct methods, i e, Forster's acetylene method for measuring the pulmonary blood flow, should be tried to re evaluate the effects of different concentrations of carbon dioxide and oxygen, to determine the critical concentrations of these substances necessary to produce changes in distribution of the pulmonary blood flow, and to determine the receptors and mechanism that mediates these changes in the lung

DR ADAMS (Closing) —I wish to thank the discussers for their constructive contributions to our paper The problem of reduced pulmonary reserve, especially with the development of pulmonary hypertension, continues to increase in frequency with the increase in life expectancy Although much has been learned about the nature of this problem, methods of management are still far from adequate Although I have been asked to present this paper, the major portion of the investigative work has been carried out by other authors on the paper

SURGICAL TREATMENT OF "ATYPICAL" PATENT DUCTUS ARTERIOSUS

William P. Young, M.D. (by invitation), George G. Rowe, M.D. (by invitation), Anthony R. Curreri, M.D., and Joseph W. Gale, M.D., Madison, Wis.

The use of cardiac catheterization has frequently established the presence of patent ductus arteriosus in the absence of the usual physical signs. These patent ductus are usually associated with pulmonary hypertension. The term "atypical" patent ductus arteriosus has come to imply the presence of associated pulmonary hypertension. The advisability of closing a patent ductus when the pulmonary artery pressure approaches or equals the pressure in the aorta has been questioned on the basis of the high operative mortality.[1, 3, 4, 14] A number of successful results, however, have been reported by these and other authors.[6, 12, 13, 16, 17]

On the other hand, closure of the uncomplicated patent ductus is safe and unquestionably indicated.[8] At the University Hospitals, patients with the typical finding of patent ductus arteriosus are corrected without cardiac catheterization or other special diagnostic procedures. In 163 uncomplicated cases in which there was ligation or division, there were 2 deaths and 2 recurrences. There were no other significant complications. Among the early cases in 1940 and 1941, there were 4 ligations carried out in the presence of subacute bacterial endarteritis. Two of these patients died and account for the deaths in the series of typical cases. One of the recurrences followed ligation with umbilical tape, and it is felt that the tie was not drawn completely tight. The second recurrence followed closure of the ductus with nonabsorbable ties and suture ligatures without dividing the ductus. It is now routine to divide all patent ductus.

It is the purpose of this paper to report surgical experience with a group of 28 patients who had patent ductus with varying degrees of pulmonary hypertension. These patients were considered preoperatively to have a patent ductus arteriosus as the only anatomic lesion. Later, 3 were shown to have concomitant congenital heart defects, and a fourth patient is suspected of having an additional defect. The accompanying table lists the preoperative

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Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

catheterization pressure in the pulmonary artery and aorta, pressures in the pulmonary artery and aorta taken at the time of surgery before and during temporary occlusion of the ductus, postoperative catheterization data, and available follow-up data. All but 1 patient had preoperative cardiac catheterization studies. The exception was a 3-month-old baby in whom a large patent ductus arteriosus was demonstrated by angiocardiogram. The cardiac catheter was passed through the ductus into the aorta in all but 2 patients, and in those 2 patients the systemic pressure was recorded from the femoral artery. Technical difficulties made some of the pressures recorded at the time of surgery unsatisfactory. For 5 of the cases, simplified pressure measurements without accurate calibration were carried out which showed only relative pressure changes. In each of these instances the systolic pressure increased *in the aorta and decreased in the pulmonary artery with temporary* occlusion of the patent ductus arteriosus. Postoperative catheterization pressures are given for 8 patients, the catheterization having been carried out from 7 to 14 months after surgery.

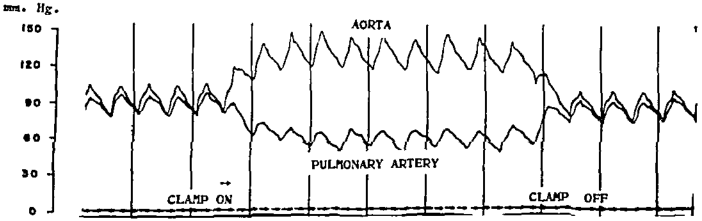

Fig. 1.—Optical recording of pressures in the aorta and pulmonary artery at surgery before, during, and after temporary occlusion of the patent ductus arteriosus. (Case 26, 12-year-old girl who had had intermittent bidirectional shunt through the ductus.) This response to temporary occlusion is very favorable. It established that the bidirectional shunt was predominantly left-to-right and also that there was a significant shunt so that the patient's hemodynamics will be improved by dividing the ductus.

The response in the pressures in the pulmonary artery and aorta during temporary occlusion at time of surgery appears to be very significant as far as the patient's prognosis is concerned. Fig. 1 shows a very favorable response to temporary occlusion. These are pressure tracings recorded in a 12-year-old girl who had had intermittent bidirectional shunt through the ductus. This response to temporary occlusion confirmed the catheterization data which indicated that the bidirectional shunt was predominantly left-to-right. It also established that the shunt was of significant volume so that the patient's hemodynamics could be improved by dividing the ductus. Varying the concentration of oxygen in the anesthetic mixture did not affect these pressures but probably would have if observation had been continued over a long period.[2]

Fig. 2 shows pressures similarly recorded in Case 5 who is now suspected of having an interventricular septal defect. Such a lack of response to occlusion of the ductus is considered an unfavorable sign in the presence

CASE NO.	AGE	SEX	PREOP. CATHETER. PRESSURES PA	PREOP. CATHETER. PRESSURES AORTA	PRESSURES TAKEN AT SURGERY DUCTUS OPEN PA	PRESSURES TAKEN AT SURGERY DUCTUS OPEN AORTA	PRESSURES TAKEN AT SURGERY DUCTUS CLOSED PA	PRESSURES TAKEN AT SURGERY DUCTUS CLOSED AORTA	POSTOP. CATHETER. DATA MO. POSTOP.	POSTOP. CATHETER. DATA PA	POSTOP. CATHETER. DATA SYSTEMIC A	LAST REPORT (MONTHS POSTOP.)	FOLLOW UP SYMPTOMS	FOLLOW UP ACTIVITY	FOLLOW UP FINDINGS
1	21	M	64/42	180/70 FA	68/38	106/62	41/23	132/103	14	29/9	140/86 FA	14	No	Full	Neg.
2	2	F	77/48	94/42	47/35	67/56	41/32	80/75				26	Alive and well (letter)		
3	9/12	F	65/39	103/61								6	No	Full	G 1 Sys. M§
4	11	F	90/57	114/60	100/80	115/78	60/47	170/115				36	Alive and well (letter)		
5	7/12	M	48/26	85/42 FA	63/32	82/51	63/32	84/50				2	No	Full	Systolic murmur; suspect VSD
6	4	F	77/40	77/40	98/93	105/90	84/78	129/114	12	66/31	82/51 FA	30	No	Full	G 1 Sys. M
7	18	F	48/34	97/50	40/28	88/53	26/9	133/80				19	No	Full	Neg.
8	2/12	F	78/60	68/50	50/43	48/43	52/43	50/47				Died 41st postop. day			Chronic passive congestion and diffuse necrosis of liver
9	2	F	52/31	124/60	*							25	No	Full	Neg.
10	11	M	58/37	94/51	45/20	90/50	30/10	100/80				1	Recovering rapidly		G 1 Sys. M
11	9/12	M	58/25	68/23	80/55	80/47	61/27	106/50	7	37/10	64/54 FA	7	No	Full	Neg.
12	1	F	70/48	83/50	67/52	85/60	52/35	120/84				1	Recovering rapidly		
13	1	F	100/40	100/50	36/30	55/42	29/25	65/47				Died 18th postop. day of pneumonia			
14	1	F	85/50	80/60		80/50		100/70				7	No	Full	G 1 Sys. M
15	9/12	F	48/20	95/63								8	No	Full	Neg.
16	2	F	86/58	86/54	40/30	71/58	29/20	93/80				33	No	Full	Neg.
17	1	M	50/25	113/73								13	No	Full	Neg.
18	5	M	48/36	131/75	*							59	Alive and well (letter)		
19	29	M	86/48	127/64	*				12	32/18	118/77 BA	12	No	Full	Huge heart† ASD and VSD
20	7/12	F	42/35	57/41	51/33	61/46	50/34	61/46				Died 2nd postop. day			
21	10	F	101/63	112/60	71/56	76/62	56/37	90/77	8	80/36	125/75 BA	23	No	Full	G 1 Sys. M VSD
22	3/12	M	Large PDA demonstrated on angiocardiogram		44/23	45/21	44/23	45/31				Died 1st postop. day			
23	9/12	M	90/52	97/60	90/54	94/60	72/49	111/70				45	No	Full	G 1 Sys. M
24	11	F	103/70	109/70	84/74	93/77	67/57	117/102	13	103/53	126/75 FA	13	No	Full	‡
25	6	M	47/24	105/60					13	25/11	93/66 FA	25	No	Full	G 1 Sys. M
26	12	F	100/63	107/62	95/75	108/75	65/41	145/115				5	No	Full	G 1 Sys. M
27	4	F	74/58	94/56	*							14	No	Full	G 1 Sys. M
28	2	M	77/44	103/44	*				11	19/7	117/65 FA	11	No	Full	Neg.

*Simplified pressure measurements without accurate calibration showing only relative pressure changes—in each instance systolic pressure increased in the aorta and decreased in the pulmonary artery with temporary occlusion of the PDA.

†Patient died 23 months postoperative after a fight. Autopsy showed enlarged heart, no defects.

‡Intermittent Grade 1 systolic murmur, RV apex beat, ECG—right ventricular hypertrophy, suspected of having another defect, was recatheterized and none was found but has severe pulmonary hypertension

§G 1 Sys. M. = Grade 1 systolic murmur.

of a ductus of significant size. The lack of response indicates the shunt through the ductus is not supporting the pulmonary hypertension and that the elevation of pulmonary artery pressure is due to an increase in pulmonary vascular resistance or another more significant shunt. When there was no pressure response to closure of a patent ductus, the prognosis in this series was poor. Three of 4 such patients died in the postoperative period. There was only one death among the other 24 patients who had a favorable pressure change with temporary occlusion of the ductus. The pressure responses do not need to be as marked as shown in Fig. 1 to be a favorable prognostic sign.

Another cardiovascular defect was found later in 3 of 4 patients who had no pressure change with temporary occlusion in the ductus. Four other patients not included in this series had patent ductus arteriosus and known septal defects. Systemic and pulmonary artery pressures were recorded while the ductus were being closed and no significant change occurred in the pressures. Considerable change, however, did take place with the closure of the septal defects. Adding these cases to the preceding group gives a total of 8 cases in which there was no pressure response to occlusion of the ductus.

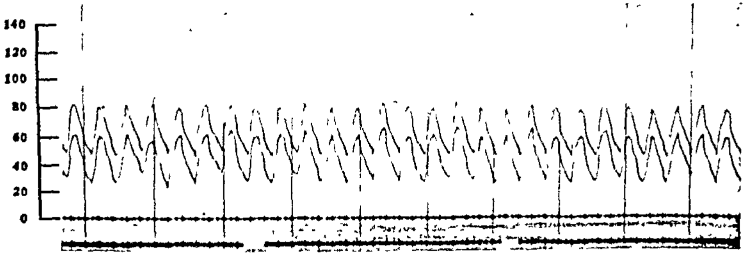

Fig. 2.—Optical recordings of pressures in the aorta and pulmonary artery at surgery before, during, and after temporary occlusion of the patent ductus arteriosus. Occlusion was established and released at the first and second breaks in the heavy line, respectively. (Case 5, 7-month-old boy.) This lack of response to occlusion is an unfavorable sign and indicates that the shunt through the ductus is not supporting the pulmonary hypertension. In this case it is suspected that there is a ventricular septal defect.

In 7 of these 8 instances, there were additional cardiac defects. The lack of pressure changes on temporary occlusion of the ductus may also be due to a balance between the systemic and pulmonary resistances but at least on theoretical grounds should be found only when the preocclusion pressures are equal in the pulmonary artery and aorta.

Many authors have described the changes in the pulmonary arteries Edwards,[5] Smith,[14] and Cosh[3] have good discussions on the subject and it will not be discussed here except to say that in the presence of pulmonary hypertension the walls of muscular arteries are frequently found to be thickened with encroachment upon the lumen. There is reason to believe that in some instances there is persistence of the fetal pattern of blood vessels and in other instances the changes in the vessels are acquired as a result of a long-standing pulmonary hypertension.

TECHNIQUE OF CLOSURE

In the technique of closing a patent ductus in the presence of pulmonary hypertension, one must be very conscious of the greater hazard of serious bleeding from a tear in the pulmonary artery. It is considered essential that the short wide ductus that have associated pulmonary hypertension be divided. Fig. 3 illustrates the technique that was used in closing many of these ductus. The aorta is dissected out above and below the ductus and umbilical tapes are passed about the aorta at these sites. The aorta is completely mobilized in the vicinity of the ductus and mobilization of the ductus is completed by dissecting medial to the aorta and ductus as suggested by Jones.[9] A moderate degree of hypothermia has been a routine for surgery for patent ductus since it was suggested by Ellis and his associates.[6] The patients were cooled to 92° to 95° F. These two procedures provide the opportunity to cross-clamp the aorta if necessary. The Potts-Smith clamp[9] is frequently used when there is pulmonary hypertension or the ductus is short and wide. In such a situation the ductus itself is allowed to remain with the pulmonary artery to facilitate its closure—the ductus being divided flush with the aorta. A tear in the pulmonary artery is more difficult to control than a defect in the wall of the aorta when the aorta is mobilized. Controlled hypotension[7] with the use of trimethaphan camphorsulfonate (Arfonad) or the cross-clamping of the aorta[6] proximal to the ductus has been used to facilitate the application of clamps. Although the longitudinal suture line in the aorta, made necessary by the use of the Potts-Smith clamp, may be less desirable than the transverse suture line, there has been no trouble with healing of the longitudinal line and no patients have been lost due to technical difficulties.

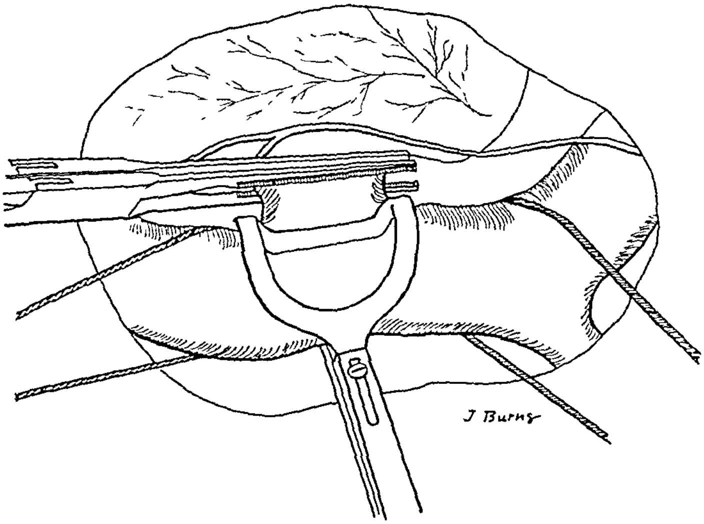

Fig. 3.—The aorta is mobilized adjacent to the ductus and tapes are passed around the aorta above and below the ductus. The vagus and recurrent nerves are carried toward the pericardium with the dissection. A Potts-Smith aortic clamp is frequently used so that the ductus may be divided flush with the aorta, permitting suturing of the ductus rather than the pulmonary artery in the presence of pulmonary hypertension.

Enlargement of the heart, pulmonary artery, and aorta may reduce the operating space about the ductus and require the employment of many of the possible safe-guards, such as hypothermia, cross-clamping the aorta, controlled hypotension, Potts-Smith clamps, placing mattress sutures before cutting through the ductus, and dividing and suturing the ductus in stages.

The data in Case 10, shown in Table I, are of unusual interest. This patient, whose proved patent ductus had been divided 7 years earlier, presented himself again and on cardiac catheterization was found to have an aorticopulmonary window with pulmonary hypertension. This window is included with the atypical patent ductus because of the identical hemodynamics With a pump-oxygenator ready, a bilateral anterior thoracotomy was made The site of the previous ductus division was dissected out and no recurrence found. Fig 4 shows the aorticopulmonary window which measured 20 mm. in diameter and was just far enough above the ventricles so that it could be divided and sutured as one divides a ductus. Controlled hypotension was used to facilitate the application of clamps and suturing. The pump-oxygenator was not used. Fig. 5 shows the suture defects in the aorta and pulmonary artery after the communication had been divided.

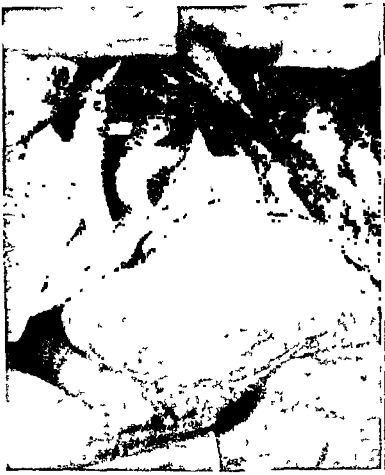

Fig 4

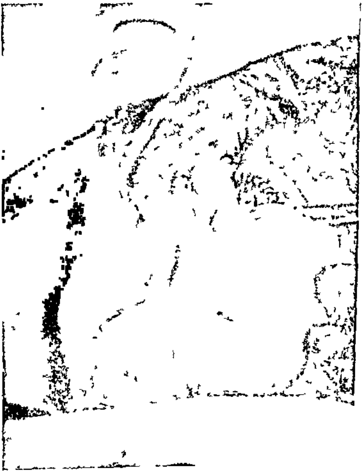

Fig 5

Fig 4.—An aorticopulmonary window is present adjacent to the ventricles The site of the window can be seen just above the proximal tape around the aorta The origin of the pulmonary artery may be seen as the ventricular musculature is retracted with the instrument (Case 10) There was moderate pulmonary hypertension

Fig 5—Aorticopulmonary window has been divided and sutured Controlled hypotension was maintained with Arfonad during the application of clamps and the suturing. A pump-oxygenator had been prepared but was not used

RESULTS

If the data on Table I is summarized, it is found [illegible] 24 of [illegible] 28 patients had favorable pressure changes to temporary c [illegible]

CONCLUSIONS

The diagnosis of patent ductus arteriosus in the presence of pulmonary hypertension is more difficult than in the absence of pulmonary hypertension. Cardiac catheterization is probably necessary to make the diagnosis and even then the demonstration of the patent ductus arteriosus may not establish that the ductus is the significant lesion.

While uncomplicated patent ductus may be closed with almost certain good results, the closure of patent ductus in the presence of pulmonary hypertension carried a higher potential mortality and less prospects of establishing normality. Surgery is much more urgently needed in the presence of pulmonary hypertension because of the probability of progressive changes in the pulmonary vascular system.

The pressure changes on temporary occlusion of the ductus merely indicate hemodynamic significance of the ductus. The presence of a significant left-to-right shunt would be signalled by a favorable response, and the presence of an insignificant shunt by no response. A predominantly right-to-left shunt would cause a rise in the pulmonary artery pressure on temporary occlusion of the ductus.

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DISCUSSION

DR HARRIS B SHUMACKER, Jr , Indianapolis, Ind —I think the subject which Dr Gale has introduced is very timely, since a pessimistic attitude still exists concerning the surgical possibilities for patients who have pulmonary hypertension associated with patent ductus arteriosus As in the case in his experience, we too do not know how many of our patients have had pulmonary hypertension, for in the earlier days not only were patients with typical signs of patent ductus not subjected to preoperative catheterization, but pressures were also not determined at operation We have, however, had experience with the treatment of 50 patients who had proved hypertension of some degree

Of these, 19 had mild pulmonary hypertension, with pulmonary artery pressures of less than 50 mm Hg systolic In this group there was one death, an unfortunate cardiac arrest occurring during bronchoscopy carried out postoperatively because of the presence of atelectasis That patients with mild pulmonary hypertension may have a lesion, which is by no means innocuous, is illustrated by the first slide which shows the very common occurrence of marked cardiomegaly

In this group of 50 patients, there were 9 in whom the systolic pressure in the pulmonary artery varied between 50 and 60 These patients all did well

There remains then a group of 22 patients in whom the pressure was systemic in the pulmonary circuit, or nearly so, patients in whom the pulmonary artery pressure was in excess of 80 mm Hg, or 80 per cent of the systemic in cases in which the systemic pressure was in a hypotensive range Unfortunately, we are unable to state how many of them had reversal of flow or the extent of reversal of flow in any given case We do know, however, that many of them had systemic pressure in the pulmonary artery and that, in at least 2, the flow was predominantly from the pulmonary artery to aorta In 1 case this was evident from the clubbing of the fingers of the left hand and both feet, and in another instance predominant reversal of flow was demonstrated by angiocardiography with injection of dye into the pulmonary artery segment Both these patients did well Incidentally, both had a slight drop in pulmonary artery pressure on clamping the ductus, and no decrease in the aortic pressure In this group of 22 patients with marked pulmonary hypertension there were two deaths One was due to a technical error, the only one in the entire group The other occurred in a patient with systemic pressure in the pulmonary artery, who was apparently making an uneventful recovery after division of the ductus when she died suddenly on the fourth day of a cause which could not be explained on clinical grounds or from post mortem study

In this group of 50 patients there were 2 who had an unusual difficulty which I would like to illustrate with this slide These patients do not have marked cardiomegaly but instead have only moderate cardiac enlargement They have a large main pulmonary artery segment with some enlargement of the proximal portions of the right and left pulmonary arteries, but without significant enlargement of the peripheral branches of the pulmonary arteries Apparently in this group, in contrast to the usual case, the normal fetal pulmonary resistance persists from the time of birth The only two deaths in this group of 22 with marked pulmonary hypertension were cases of this sort, the only two of this kind we have treated surgically Perhaps this group may prove a more difficult problem than the other in which we assume that pulmonary vascular sclerosis gradually develops as the result of increased flow through the pulmonary circuit

We too have felt, particularly since the one tragic operative death to which I referred, that every effort should be made to gain control of the parent vessels in operating on a patent ductus, and we use the illustrated technique in all cases, no matter how simple, isolating the aorta above and below the ductus and, whenever the ductus is large and pulmonary hypertension exists, dividing the ductus in stages, suturing both sides as the division is completed

I do not know whether in cases of very long standing patent ductus with reversal of flow, the patient will subsequently undergo improvement in the p sclerosis, but I do know that this does occur in some children It that no patient should be considered categorically inoperable because of evidence of systemic pressure in the pulmonary circuit nor reversal of flow. It would be my feeling that any such patient should be explored. At operation a favorable pressure response may be demonstrated, as occurred in some of our patients and, if not, I would certainly be in favor of providing the patient with a smaller shunt and taking down the larger natural one, a mechanism of handling the problem which Dr. Muller and Dr. Kattus suggested some years ago.

DR. WILLIS J. POTTS, Chicago, Ill.—In keeping with the President's address which included some reference to word derivations, I would like to say something about the word "ductus." The plural of ductus is ductus. Those of you who were exposed to Latin will remember the fourth declension—the key word in my book was fructus. Ductus belongs in the same category and we properly speak of one ductus or a hundred ductus. It sounds a bit unfamiliar but that's the way it is to those who take their Latin seriously.

Pulmonary hypertension as a complication of patent ductus is a serious problem. Our experience parallels that of the speaker. Interestingly enough, if at operation the pulmonary pressure drops a little, as much as 10 mm. Hg, when the ductus is clamped, the child will do well after division and suture. On the contrary, if pulmonary pressure goes up as much as 10 mm. Hg when the ductus is clamped, results after division and suture will be bad.

We have operated upon a number of children with increased pulmonary pressure but in only 5 did the pressure go up in the pulmonary artery when the ductus was clamped. The ages of these children varied from 4 to 12 years. Knowing that the future of a child with severe hypertension is rather hopeless we divided the ductus in all 5 patients. Our hopes that reversal of pressure might occur because of the age of our patients were not realized. Two died suddenly, one 6 months, the other 2 years after surgery. Two are cardiac cripples in and out of decompensation and constantly on digitalis. The fifth child, aged 12 years, had equal systemic and pulmonary pressure and died on the operating table of hemorrhage. The pulmonary artery was 2.5 inches—not centimeters—in diameter, the ductus approximately 15 mm. in diameter. I put a clamp on the ductus and shortly thereafter the pulmonary artery ruptured. That was a mistake. What I should have done was exactly what was suggested today—an aortic clamp (Potts-Smith) should have been placed around the aorta to occlude the aortic end of the ductus close to the aortic wall. A ductus clamp then could have been placed on the pulmonary end of the ductus without causing tension and rupture. We pay so dearly for our mistakes.

Incidentally, this has been our only operative or hospital death in 495 cases of surgical occlusion of patent ductus. When a discussion of mortality comes up I note in the surgical staff an ill-concealed look of satisfaction that this lone catastrophe should have happened to me.

DR. YOUNG (Closing).—I want to thank Dr. Shumacker and Dr. Potts for their remarks. We have felt that the patients who died after their ductus were closed, and they had no change in pressures on occlusion of their ductus, died because the lesions corrected were not hemodynamically significant. Two of these patients had septal defects in addition to the ductus. The significant lesions probably were left uncorrected.

Our catheterization laboratory has found only 1 patient with patent ductus arteriosus and a marked reversal of flow. She was not subjected to surgery.

This slide shows an indicator dilution curve with evidence of a right-to-left shunt. The interrupted slope of the initial deflection in the cuvette recording from the femoral artery is due to the right-to-left shunt.

With control of polycythemia, and then repeating cardiac catheterization, a few more patients might be benefited by closure of the ductus, when they had predominantly right-to-left shunts prior to control of the polycythemia.

ANEURYSMS OF THE THORACIC AORTA

Analysis of 179 Patients Treated by Resection

Michael E DeBakey, M D , Denton A Cooley, M D , E Stanley Crawford, M D (by invitation), and George C Morris, Jr , M D (by invitation), Houston, Texas

DURING the 7 year period since our first successful resection of an aneurysm of the thoracic aorta, this method of therapy has been employed in 179 cases This report is concerned with certain observations derived from an analysis of this experience, particularly in relation to methods of resection and to factors bearing upon risk of operation Although the underlying principle of therapy consisting essentially in excision of the aneurysm is similar for all cases, the method of its application varies in accordance with the type and location of the lesion Accordingly, the cases are classified into four categories, namely, aneurysms of the descending thoracic aorta, aneurysms of the aortic arch, thoracoabdominal aneurysms, and dissecting aneurysms

ANEURYSMS OF THE DESCENDING THORACIC AORTA

This group, comprising 73 cases, represents the largest in the series and reflects the relative frequency of involvement of this segment of thoracic aorta The great majority of these aneurysms were fusiform in character, varying in size from relatively small, well localized lesions to large, extensive aneurysms that involved virtually the entire descending thoracic aorta (Figs 1 and 2) Their site of involvement was also variable, although approximately 90 per cent were located in the proximal portion of the descending thoracic aorta Contrary to earlier reports that syphilis is the most common etiological factor for aneurysms of the thoracic aorta, in this series arteriosclerosis was the most common cause and syphilis was second in frequency, the respective incidences being 47 per cent and 32 per cent (Table I)

The age of these patients ranged from 10 months to 70 years, but most of them, 83 per cent, were in the fifth to seventh decades The male sex was predominant in a ratio of about 3 to 1

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In the application of excisional therapy for aneurysms located in this portion of the aorta, the most important consideration stems from the necessity for temporary arrest of aortic circulation through the segment to be resected and the consequent effect of increased vascular resistance upon the

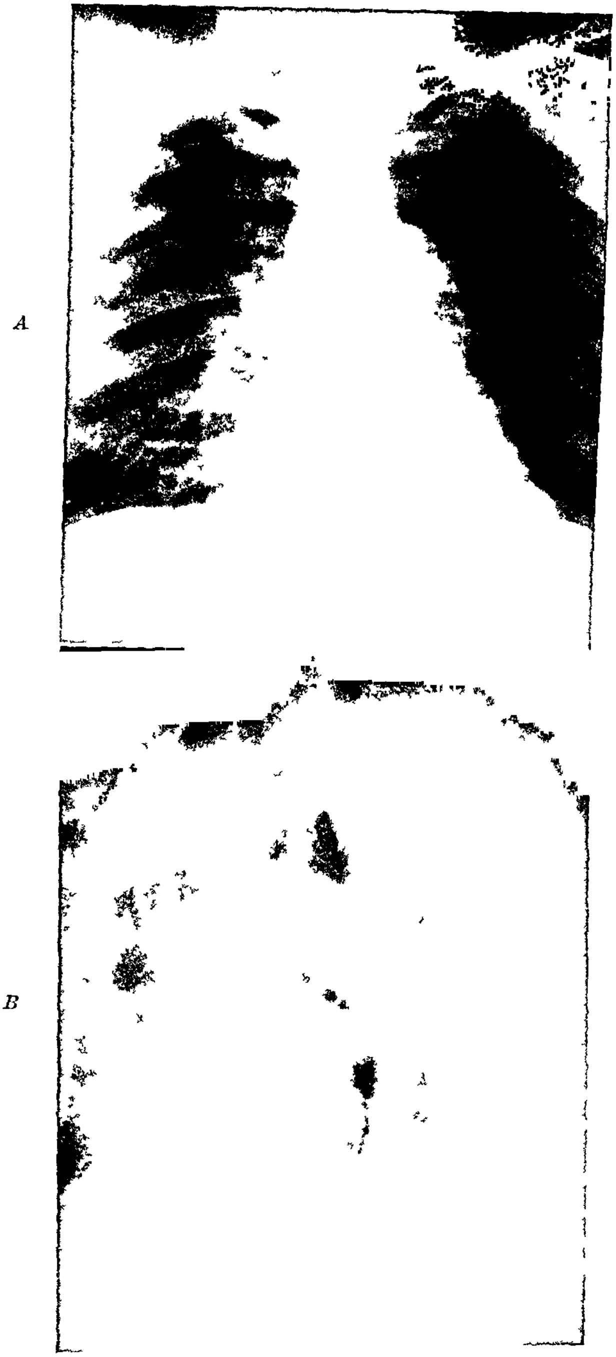


Fig. 1.—*A*, Roentgenogram of chest showing rounded shadow, outlined by peripheral rim of calcification, projecting into left lung field from mid-mediastinal region representing traumatic aneurysm of proximal segment of descending thoracic aorta. The esophagus which is demonstrated by swallowed barium is displaced to right by aneurysm.

B, Angiocardiogram of same patient showing precise location and extent of aneurysm.

heart and ischemic damage upon the spinal cord. Accordingly, control of these factors, and particularly prevention of spinal cord damage, assumes considerable significance. This may be achieved by several methods, including hypothermia, which in our early experience was the primary means used for

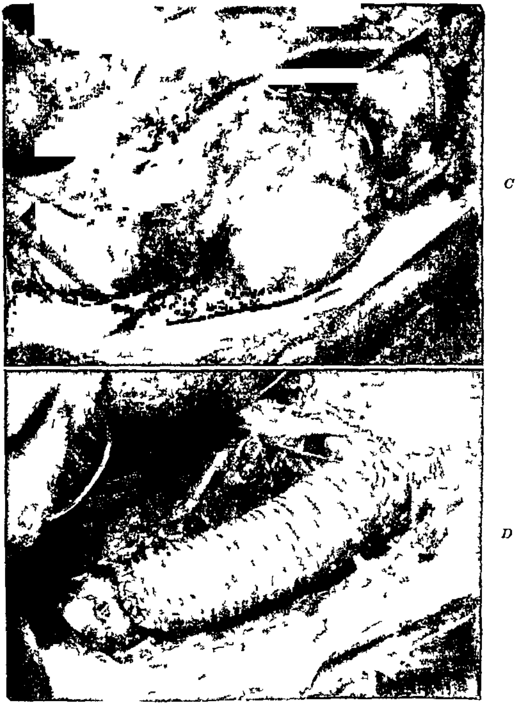


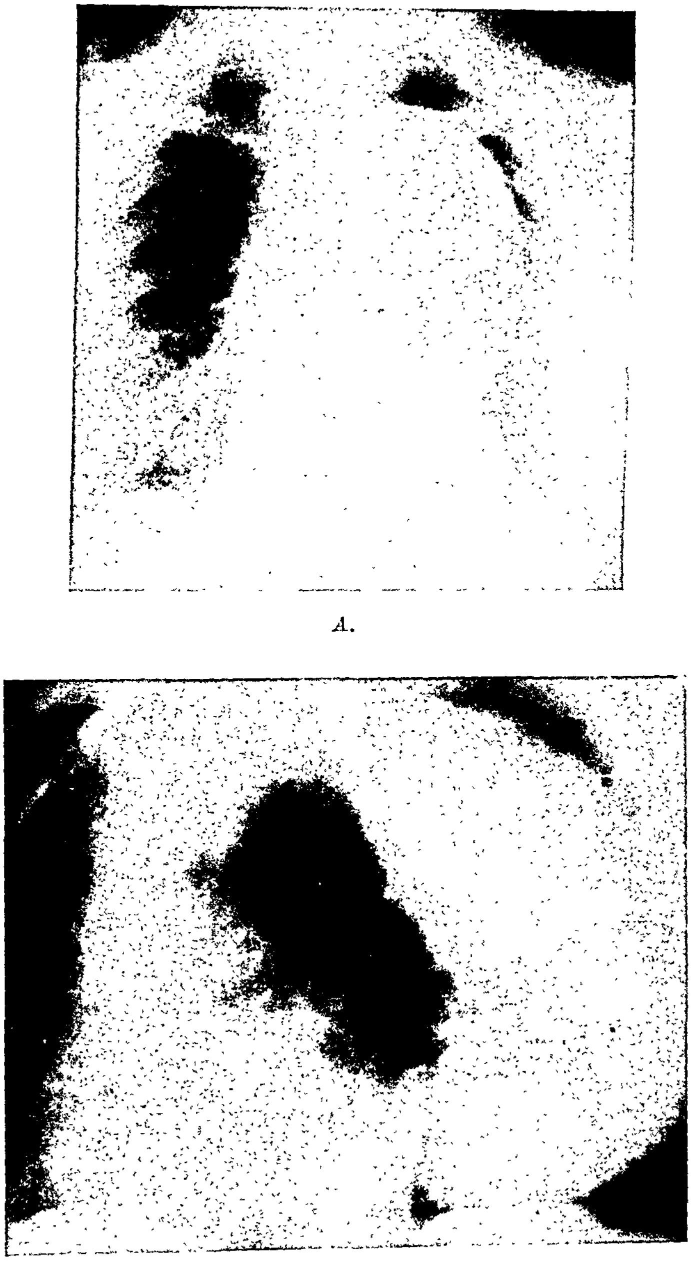
Fig. 1.—Cont'd. *C*, Photograph of same patient made at operation showing characteristic gross appearance of traumatic fusiform aneurysm of proximal portion of descending thoracic aorta following its mobilization from surrounding structures with umbilical tapes encircling aorta above (at right) and below aneurysm.

D, Photograph in same patient made at operation showing completed replacement of resected segment of aorta and aneurysm with knitted crimped Dacron graft.

TABLE I. FUSIFORM ANEURYSMS OF DESCENDING THORACIC AORTA: MORTALITY ACCORDING TO ETIOLOGY

ETIOLOGY	NO. CASES	DEATHS	
		NO. CASES	PER CENT
Arteriosclerosis	34	12	35
Syphilis	23	4	17
Trauma	9	0	0
Undetermined	7	1	14
Total	73	17	2[illegible]

this purpose. Although in general, hypothermia was found to be effective in preventing neurological sequelae, it was associated with certain well-recognized disadvantages indicating the need for a better method. This led to the development of the method of controlled extracorporeal circulation consisting essentially in the use of a pump-bypass in which oxygenated blood is


A.

B.

Fig. 2.—*A*, Roentgenogram of chest of 59-year-old white male patient showing large oval shadow projecting from mediastinum into left lung field, representing extensive arteriosclerotic fusiform aneurysm involving virtually entire descending thoracic aorta.

B, Angiocardiogram in same patient showing aneurysm arising just distal to left subclavian artery and extending down to involve distal portion of descending thoracic aorta with pronounced elongation and kinking of aorta.

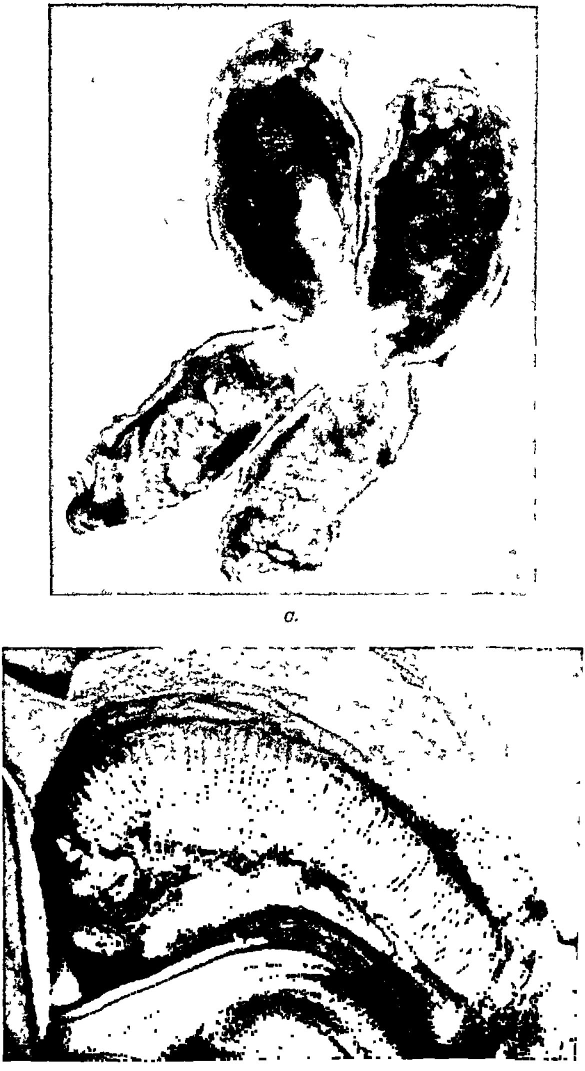


Fig. 2—Cont'd *C*, Photograph of sagittal section of specimen removed at operation in same case showing gross pathologic features of arteriosclerotic fusiform aneurysm Specimen is shown in two parts because its removal at operation was facilitated by dividing it in this manner.

D, Photograph made at operation in same patient showing completed re[illegible]t of sected segment of aorta and aneurysm with Dacron graft (pr[illegible] to removed from the left auricle and pumped into the aorta distal to the occluding clamps through a plastic cannula inserted upward into the left femoral artery[4] (Fig. 3). Immediately before insertion of these cannulas, heparin (1.0 mg./Kg. body weight) is administered intravenously and, after completing the procedure of resection and graft replacement, a counteracting dose of protamine sulfate is administered. During the period of occlusion the rate of flow is adjusted from time to time to maintain blood pressure in the arm approximately 10 to 20 mm. Hg above normal systolic pressure. In general it was found that on this basis flow rates ranging from about 1,200 to 2,500 c.c. per minute were provided. While optimum rates of flow have not been well established, our studies on renal function would suggest that it is desirable to provide sufficient volume of flow in the distal aortic segment to maintain pressure at or above 32 mm. Hg, since demonstrable renal function disappears below this level.[14] Such levels of pressure may be obtained in most instances by flow rates above 20 c.c. per kilogram of body weight.

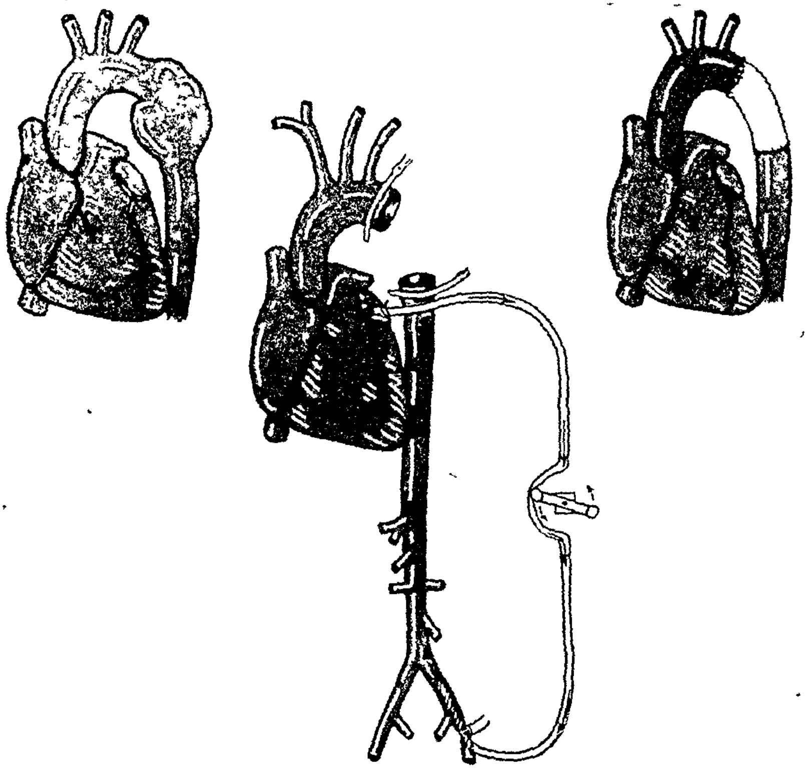


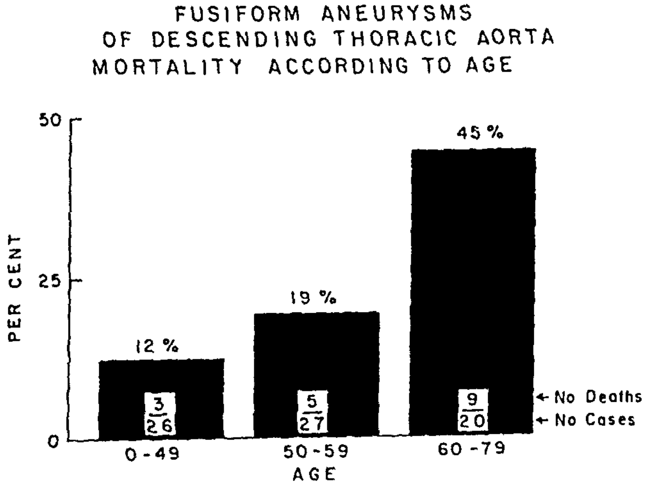
Fig. 3.—Drawing illustrating operative procedure of resection of fusiform aneurysm of descending thoracic aorta using method of controlled extracorporeal circulation to combat ischemic effects of temporary arrest of aortic circulation during performance of procedure. Oxygenated blood is removed from left auricle by means of plastic catheter inserted through appendage and pumped into distal aorta through catheter inserted into left common femoral artery.

This method was found to be more satisfactory than those previously employed and for this reason it has been applied in the last 36 cases in this series. This conviction is supported by a comparison of the results obtained in this group of cases with those in the earlier series of 37 cases in which other methods, including hypothermia, were employed. Thus, the mortality was reduced from 27 per cent in the earlier series of 37 cases to 19 per cent in the more recent series of 36 cases. In both series of cases, however, there were 2 patients in whom some manifestations of spinal cord damage occurred. The occurrence of the neurological disturbances in these 4 patients remains a rather puzzling phenomenon. This is particularly true for the 2 patients in the more recent series since the extent of segment resected, the period of occlusion, and the pump bypass flow rates were not significantly different from the other cases in which no neurological disturbances occurred. To add further to the difficulty of explaining this phenomenon is the fact that no such neurological disturbances occurred in 1 patient in this group in whom resection and graft replacement was performed for a fusiform aneurysm of the proximal segment of the descending aorta under normothermic conditions and without pump-bypass. In this case, the aneurysm ruptured during the initial dissection and it became urgently necessary to apply occluding clamps to the aorta proximal and distal to the aneurysm. Despite the fact that the aorta was occluded at this high level for 32 minutes, the patient recovered without any neurological disturbances. It would, thus, appear that considerable variations exist in tolerance of the spinal cord to temporary aortic occlusion and that a number of factors play a role in this phenomenon, including variations in the anatomic pattern and segmental distribution of spinal arteries, development of collateral circulation, as well as measures to combat temporary interruption of blood supply to the cord.

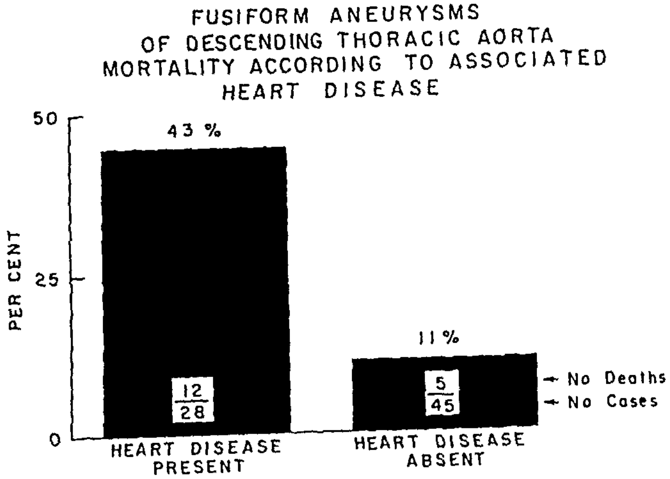
Results of excisional therapy for this type of aortic aneurysm have been increasingly gratifying as exemplified by the progressive decrease in operative mortality rate from 27 per cent in our early experience to 19 per cent in our most recent experience. This observation lends support to the conviction that improvements in the surgical management of these patients, as well as in the actual technical performance of the operation derived from increasing experience, should permit further reduction in the risk. The significance of certain factors in relation to the mortality is illustrated by further analysis of our experience. Among these factors, advancing age, etiology, hypertension, and pre-existing heart disease are particularly significant. The fatality rate, for example, in patients in the seventh and eighth decades of life was more than 2 to 3 times greater than that of younger patients (Graph I). The significance of etiology is demonstrated by the fact that the mortality among patients with aneurysms of arteriosclerotic origin was more than twice that of patients with aneurysms of other causes (Table I). To some extent this may be attributable to the fact that the patients with arteriosclerotic aneurysms were older than the others. The importance of hypertension is demonstrated by the fact that the risk in this group of patients was two times greater than that in the normotensive series (Table II). Similarly the mortality rate in patients with pre-existing heart disease was almost four times greater than that in patients without heart disease (Graph II). The importance of this factor is further emphasized by the fact that, [illegible] the [illegible]erative deaths,

TABLE II. FUSIFORM ANEURYSMS OF DESCENDING THORACIC AORTA MORTALITY ACCORDING TO BLOOD PRESSURE

BLOOD PRESSURE	NO. CASES	DEATHS	
		NO. CASES	PER CENT
149/89 or less	39	6	15
150/90 or more	34	11	32
Total	73	17	23



Graph I.



Graph II.

heart failure, mostly in the form of coronary thrombosis, was the most common cause, accounting for 9 fatalities. Among the remaining operative deaths, 2 were attributable to shock, 2 were caused by subsequent rupture of the homograft, 1 to pre-existing septicemia, 1 to massive upper gastrointestinal hemorrhage, and 2 to complications of an associated aneurysm of the abdominal aorta. In one of these latter cases in which the operation was performed under hypothermia, it was noted immediately following completion of the resection of the thoracic aneurysm that all pulses in the lower extremity were

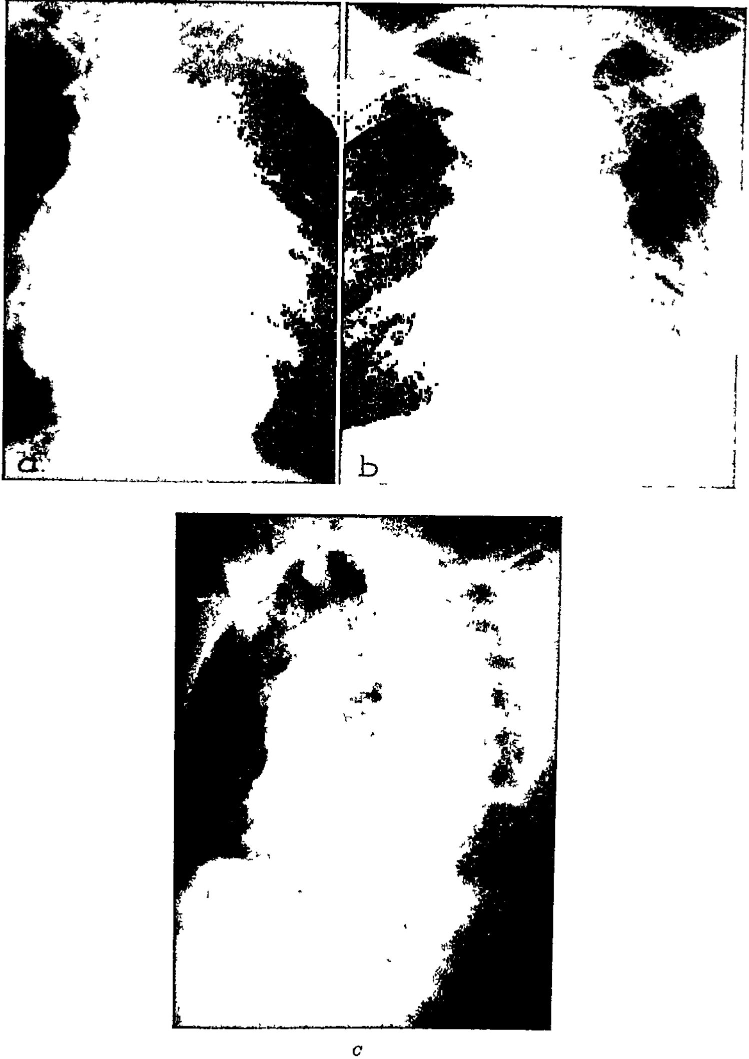


Fig. 4.—*A*, Preoperative roentgenogram of chest in a 50-year-old Negro man showing extensive syphilitic fusiform aneurysm of descending thoracic aorta (case report on this patient was previously presented[2])

B, Roentgenogram of chest in same patient made approximately 5 years after operation consisting of resection and homograft replacement of aneurysm. Patient has remained well and resumed completely normal activities

C, Angiocardiogram in same patient made approximately 5 years after operation showing relatively normal outline of descending thoracic aorta.

absent and a saddle embolus of the aortic bifurcation was suspected. Immediate abdominal exploration revealed, however, the presence of a small fusiform aneurysm of the abdominal aorta which had become completely occluded by thrombus, presumably formed during the period of thoracic aortic occlusion. It was resected and replaced by a homograft and, although circulation was restored in the lower extremities, the patient died of renal failure and uremia on the eighth postoperative day. In the other case, the associated aneurysm of the abdominal aorta was diagnosed preoperatively and resection of the aneurysm of the thoracic aorta was performed first. Although the patient's immediate postoperative course was satisfactory, acute rupture of the aneurysm of the abdominal aorta occurred 36 hours later causing rapid death. Of further interest in this connection is the fact that there were 4 other patients in this series who also had an associated aneurysm of the abdominal aorta which was successfully resected at a previous operation.

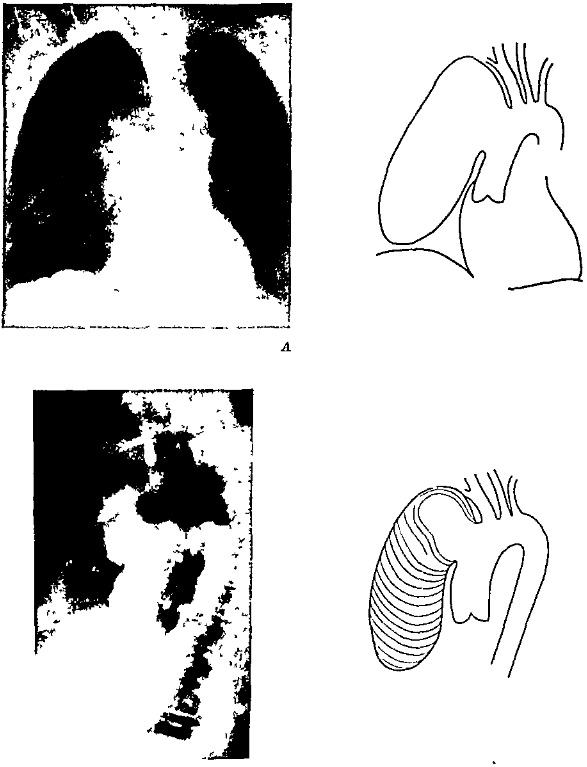
Follow-up observations on all the surviving patients in this group extending for periods ranging from several months to over 5 years provide highly gratifying results. With few exceptions there has been complete relief of symptoms and resumption of normal activities. Of particular interest is the fact that the first 2 patients in this series, in whom operation was performed approximately 5 years ago, have remained well and working.[2, 7, 8] An angiocardiogram performed recently in 1 of these patients whose case report appeared in a previous publication[2] reveals a relatively normal outline of the descending thoracic aorta (Fig. 4). There have been 8 late deaths in this group occurring from a few months to about 1½ years after operation. Three of these deaths were due to heart disease, 1 to cerebrovascular thrombosis, 1 to pneumonia, and 3 to complications of the graft replacement. Among this latter group, 2 were due to aneurysm formation and rupture of the homograft, one 5 months and the other 7 months after operation. In the third case, Ivalon was used as the graft replacement and death occurred 3 months after operation from infection, mediastinal abscess, and secondary hemorrhage. In this connection, it may be significant that none of these graft replacement complications have been encountered since we have employed the crimped, knitted Dacron arterial replacement.

ANEURYSMS OF THE AORTIC ARCH

This group, comprising 50 cases, represents the most serious form of aortic aneurysm not only because of the gravity of this disease but also because of the inherent difficulties involved in the application of excisional therapy. Syphilis was the predominant etiological factor, being present in 35 cases while, in the remainder, the underlying cause was considered to be arteriosclerosis in 10, trauma in 3, and undetermined in 2 (Table III). The ratio of males to females was 4 to 1 and the majority of the patients were in the sixth and seventh decades of life. Although 26 cases were sacciform in type and 24 fusiform, in both instances there was considerable variation in size from relatively small, well-localized lesions to large extensive aneurysms involving virtually the entire arch (Figs. 5, 6, 7, 8).

TABLE III. ANEURYSMS OF AORTIC ARCH
MORTALITY ACCORDING TO ETIOLOGY

ETIOLOGY	NO. CASES	DEATHS	
		NO. CASES	PER CENT
Syphilis	35	19	54
Arteriosclerosis	10	8	80
Trauma	3	1	33
Undetermined	2	0	0
Total	50	28	56

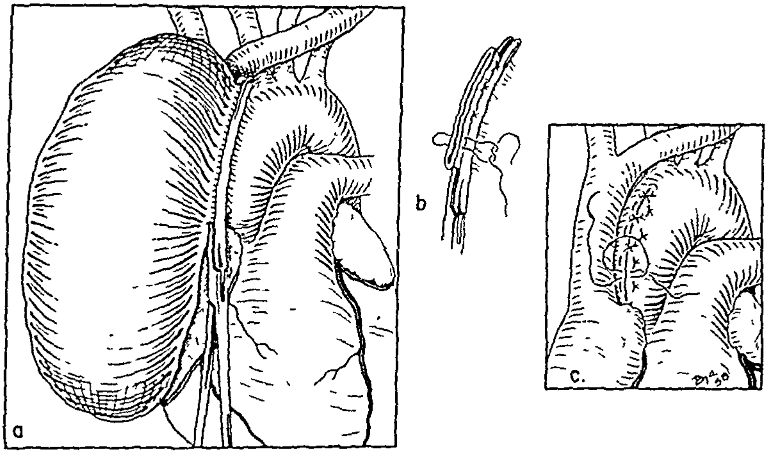


A

B.

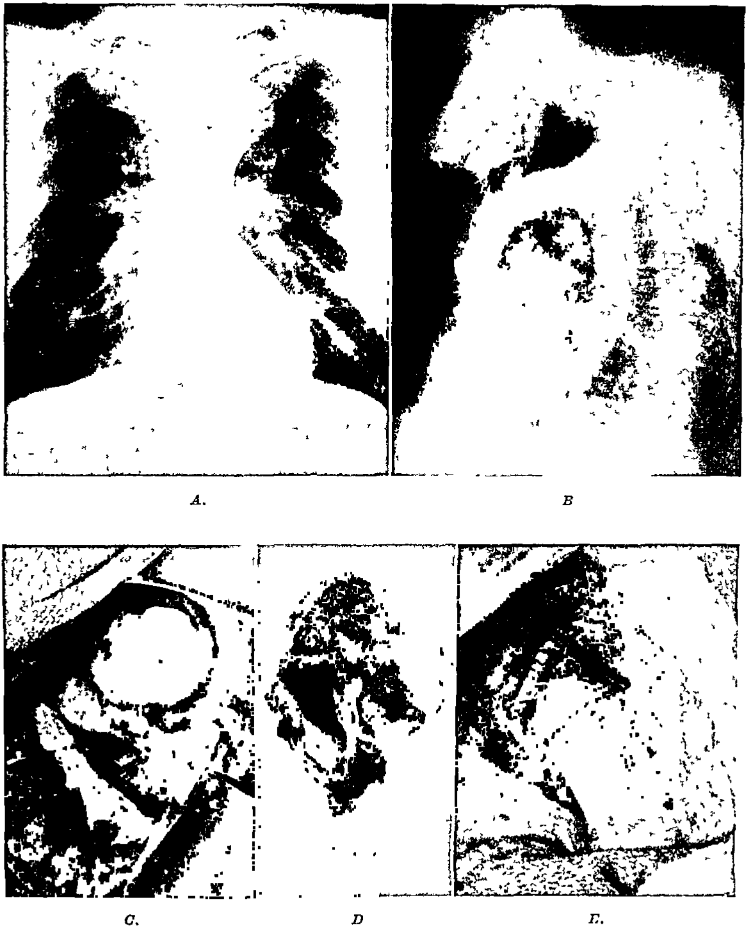
[illegible] chest of patient showing large shadow projecting into right lung [illegible] sacciform aneurysm with relatively narrow neck arising from [illegible] diagram on right. *B*, Angiocardiogram in same patient showi[illegible] eye, precise location of neck of sacciform aneurysm arising from [illegible] by diagram on right, most of lumen of sac is filled with thrombus.

Several methods of excisional therapy may be employed for this group of aneurysms depending upon the location and nature of the lesion. In certain forms of sacciform aneurysms, for example, in which the neck of the sac is relatively small, the procedure of tangential excision and aortorrhaphy may be the most satisfactory[1] (Fig. 5*C*). Even in cases in which the sac itself is quite large and extensive, this procedure may be effectively applied so long as the neck is relatively narrow and involves less than half the circumference of the aorta (Fig. 5). In fusiform aneurysms, however, or in sacciform aneurysms in which the neck of the sac encroaches upon a considerable segment of the aortic circumference, extirpational therapy requires resection of the entire segment of the diseased aorta with graft replacement (Fig. 6). The necessity for temporary arrest of aortic circulation in the performance of this procedure imposes serious problems. For one thing, arrest of circulation at this level interrupts cerebral blood flow which, even after a few minutes, can produce fatal ischemic damage to the central nervous system. For another, occlusion of the ascending aorta rapidly imposes such a serious strain upon the left ventricle that acute cardiac failure may ensue. To overcome these problems, several methods may be employed depending upon the location of the lesion. Thus, for aneurysms involving the transverse arch or the distal portion of the ascending aorta the use of temporary shunts is considered the procedure of choice (Figs. 7 and 8). In such cases in which the proximal portion of the ascending aorta is uninvolved, it is possible to apply the shunt proximal and distal to the lesion by end-to-side anastomosis, using a partial occlusion clamp on the aorta and thus to perform the procedure without interruption of circulation at any time (Figs. 7 and 8). In our early experience with this bypass principle, the materials used for this purpose were of such nature as to permit their application as temporary shunts only, and following the procedure of resection and graft replacement they were removed.[5,6] More recently, however, with the development of the crimped Dacron tube, it has become possible to employ this bypass principle



C.

Fig. 5.—Cont'd. *C*, Drawing illustrating procedure of tangential resection and aortorrhaphy which was successfully performed in this patient.



A. *B*

C. *D* *E.*

Fig 6 —*A*, Roentgenogram of chest showing rounded shadow in upper left mediastinum representing sacciform aneurysm of proximal segment of descending thoracic aorta

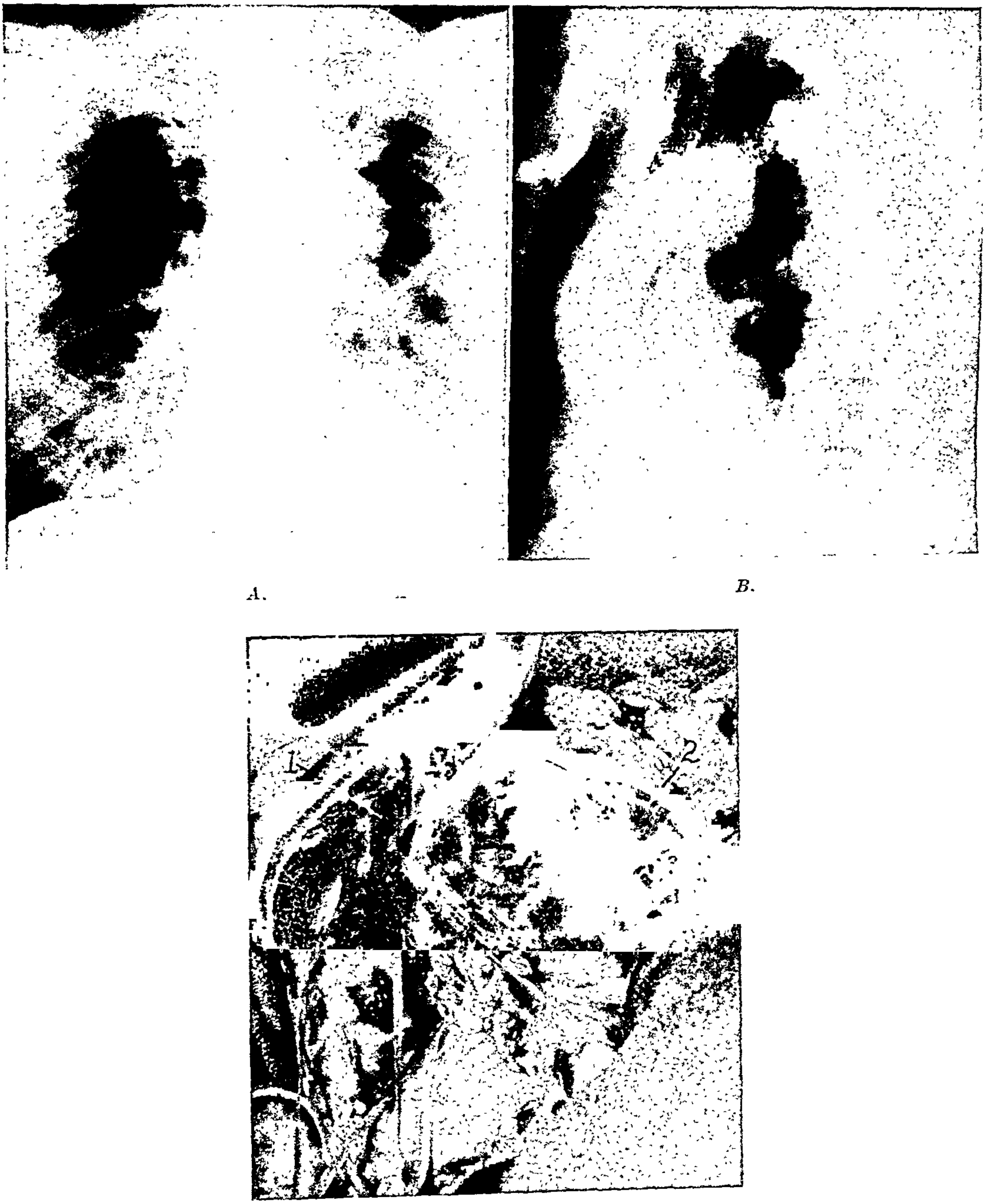
B, Angiocardiogram in same patient showing precise location and intraluminal dimensions of sacciform aneurysm

C, Photograph made at operation in same patient showing gross appearance and anatomic relationship of sacciform aneurysm of descending limb of aortic arch

D, Photograph of excised segment of aorta involved by the aneurysm

E, Photograph made at operation in same patient showing completed replacement with Dacron "graft" (This is one of 4 patients with aneurysms of the thoracic aorta in this series who also had successful resection of an aneurysm of the abdominal aorta) in a manner that permits its application both as a temporary and a permanent shunt (Figs. 7 and 8). This is a distinct advantage in reducing the extent of the surgical procedure and the hazards of the operation.

In cases in which the aneurysm involves the proximal portion of the ascending aorta excisional therapy requires the use of the cardiopulmonary



A.

B.

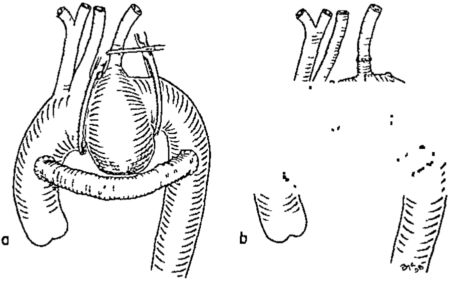
C.

Fig. 7.—*A*, Roentgenogram of chest showing rounded shadow projecting from mediastinum into left lung field representing fusiform aneurysm of transverse arch of aorta.

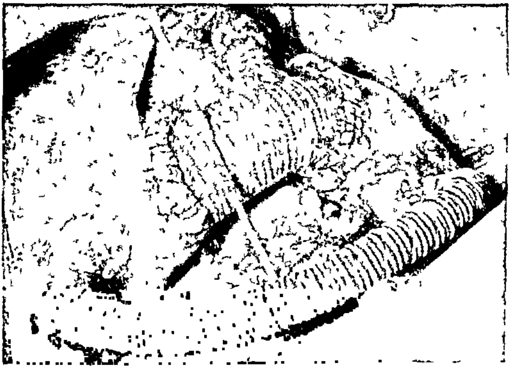
B, Angiocardiogram showing extent and location of aneurysm.

C, Photograph made at operation showing extent and location of aneurysm involving transverse arch between (*1*) left common carotid artery and (*2*) descending limb of aortic arch.

bypass method by means of an artificial heart-lung apparatus (Fig. 9). Details concerning the application of this method have been described in previous reports.[3, 10]



D.



E

Fig. 7.—Cont'd *D*, Drawing showing method of temporary bypass from ascending to descending aorta employed for resection of this type of aneurysm

E, Photograph made at operation showing completed procedure of resection with replacement by Dacron graft including anastomosis to left subclavian artery and use of bypass Dacron graft from ascending aorta to descending limb of aortic arch

Analysis of results of operation in this group of aneurysms reveals a number of factors having a significant bearing upon the operative risk, including particularly the type and location of the aneurysm, age, and the method of excisional therapy. Aneurysms of arteriosclerotic origin, for example, were associated with a considerably higher operative mortality than other types of lesions, owing probably to the fact that these patients were more advanced in age and were more likely to have associated heart disease (Table IV). The importance of the type and extent of the aneurysm is demonstrated by the fact that the operative mortality in [illegible]

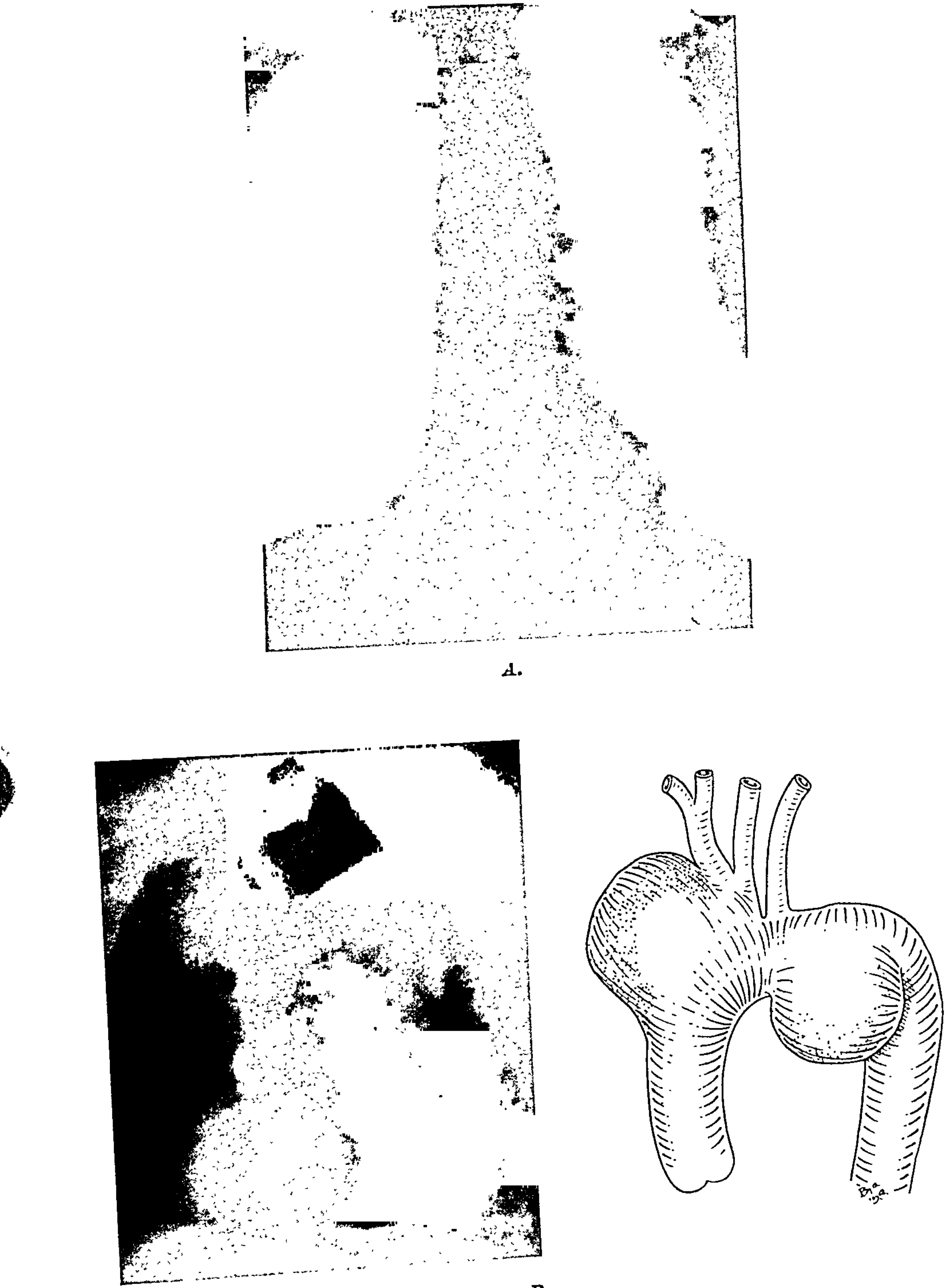
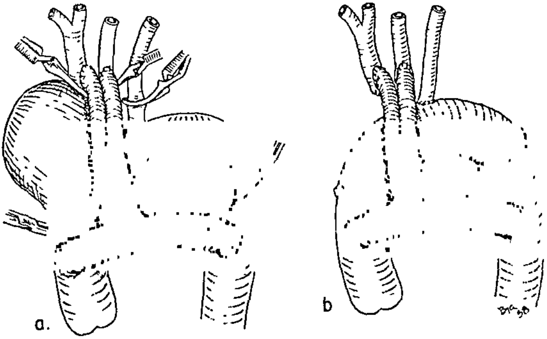


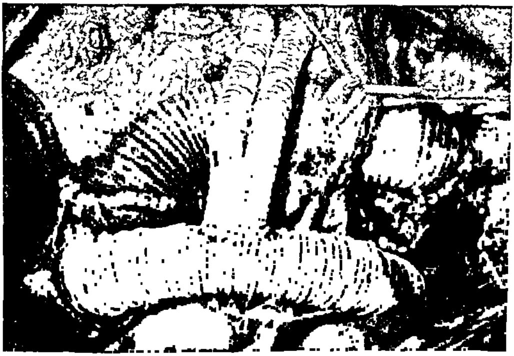
Fig. 8.—*A*, Roentgenogram of chest showing supracardiac mediastinal shadow representing extensive fusiform aneurysms of aortic arch.

B, Angiocardiogram of same patient showing precise location of aneurysms involving distal part of ascending aorta and transverse arch as indicated in drawing on right.

75 per cent, whereas among sacciform aneurysms it was only 28 per cent. The significance of age is indicated by the fact that among the 16 patients in the seventh decade of life the operative mortality was 75 per cent, whereas among the remaining patients below this age it was 47 per cent.



C.



D.

Fig. 8.—Cont'd. *C*, Drawings illustrating method of resection and graft replacement using method of temporary bypass subsequently converted into permanent graft.

D, Photograph made at operation showing completed procedure.

TABLE IV. DISSECTING ANEURYSMS OF THORACIC AORTA
MORTALITY ACCORDING TO AGE

AGE	NO. CASES	NO. DEATHS
30-39	2	0
40-49	13	5
50-59	7	2
60-69	10	2
70-79	2	1
Total	34	10 (29%)

Although the total mortality of 56 per cent in this group of patients is relatively high, it must be evaluated against the background of the extreme gravity of the natural course of this disease. Moreover, there is reason to believe that with increasing experience in the surgical management and with technical improvements in the performance of the operation, the operative risk should be steadily reduced. Among the surviving patients, the results have been highly gratifying with complete relief of symptoms and restoration of normal activity.

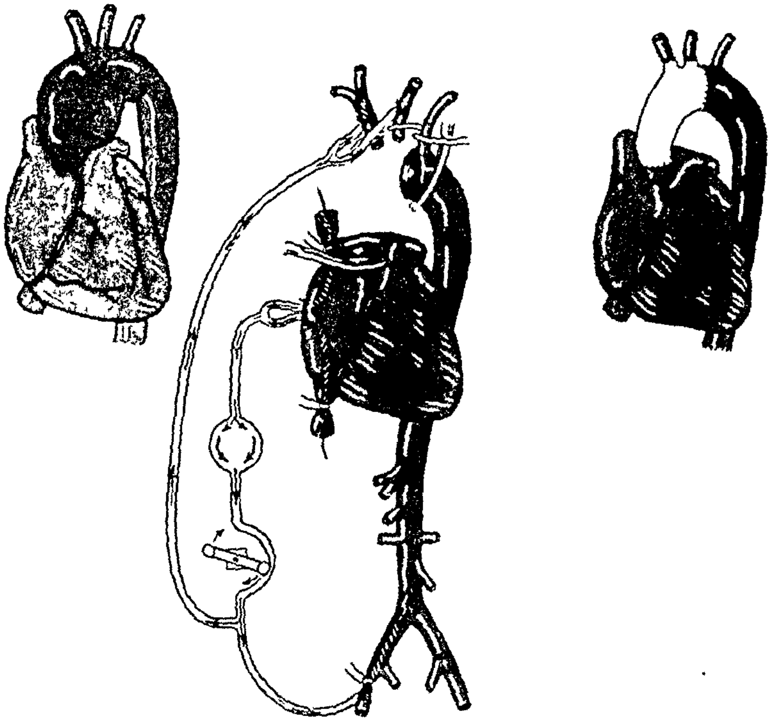


Fig. 9.—Drawing showing method of resection and graft replacement for fusiform aneurysms involving proximal part of ascending aorta using cardiopulmonary bypass by means of artificial heart-lung apparatus.

THORACOABDOMINAL ANEURYSMS

Aneurysms located in this segment of the aorta derive significance from the fact that they involve the principal vessels to the abdominal viscera (Fig. 10). Accordingly, excisional therapy of these lesions is associated with considerable danger of producing fatal ischemic damage to such vital structures as the liver, kidneys, and gastrointestinal tract, as a consequence of temporary arrest of blood flow to these organs during the period of resection and graft replacement.

Syphilis was the predominant cause of this group of aneurysms, being present in 15 of the 22 cases. Among the remainder there were 3 of arteriosclerotic, 2 of traumatic, and 2 of congenital origins. All but 2 of the cases were males, and most of the patients were in the fifth, sixth, and seventh decades of life.

As previously indicated, the most important consideration in extirpation of aneurysms of this type arises from the potential ischemic damage to the abdominal viscera as a consequence of temporary arrest of circulation during performance of the procedure.[11] Moreover, there is reason to believe that the kidneys represent the most sensitive abdominal organs to ischemia. To overcome this problem, several methods may be employed, including hypothermia, controlled extracorporeal circulation, and temporary shunts. The latter 2 methods were found to be satisfactory in achieving this objective and have been described in previous reports.[4, 11] More recently, still another method has been developed which is considered to have additional advantages (Fig. 11). This method was made possible through the use of our crimped, knitted Dacron tube which permits conversion of the temporary shunt into the permanent graft.

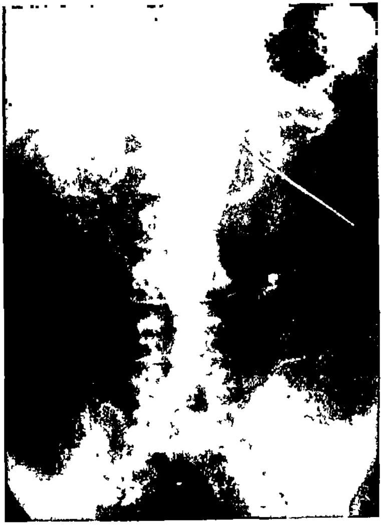


Fig. 10.—Aortogram showing fusiform aneurysm arising in distal segment of descending thoracic aorta and extending down to involve upper segment of abdominal aorta including celiac superior mesenteric, and renal arteries.

In the application of this method, the Dacron tube, which is provided with branches for the celiac, superior mesenteric, and renal arteries, is attached by end-to-side anastomosis using partial tangential occlusion clamps to the descending thoracic aorta immediately above the aneurysm and by end-to end anastomosis to the abdominal aorta below the aneurysm (Fig. 11, *a*). The left renal artery is then detached from its aortic origin and the distal end is sutured by end-to-end anastomosis to the corresponding branch on the Dacron tube (Fig. 11, *b*). Following completion of [illegible] p[illegible]dures the occlusion clamps are released, permitting blood flow through the Dacron tube to the left renal artery and the abdominal aorta distally. By this means circulation to the left kidney is arrested for a period of about 10 or 15 minutes. Circulation through the aneurysm is then arrested by applying occluding clamps to the celiac, superior mesenteric, and right renal artery, as well

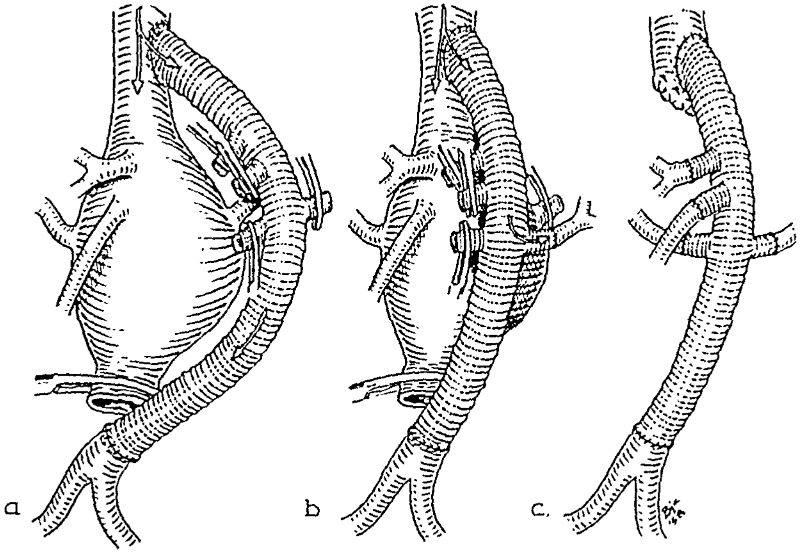


Fig. 11.—Drawing showing method of resection and graft replacement in thoracoabdominal aneurysms using crimped, knitted Dacron tube which permits conversion of the temporary shunt into permanent graft.

a, Dacron tube is attached to descending thoracic aorta above aneurysm by end-to-side anastomosis and to abdominal aorta below aneurysm by end-to-end anastomosis.

b, Left renal artery is attached to corresponding branch on Dacron tube by end-to-end anastomosis and blood flow restored to left kidney. Occluding clamps are then applied to remaining visceral branches and to aorta above aneurysm but below proximal end-to-side anastomosis of Dacron tube, and aneurysm is excised.

c, End-to-end anastomosis is then performed between respective branches of Dacron tube and right renal, superior mesenteric, and celiac arteries, in that order, with restoration of circulation following completion of each anastomosis. Procedure is completed by suture closure of distal end of thoracic aorta immediately below end-to-side anastomosis of Dacron tube.

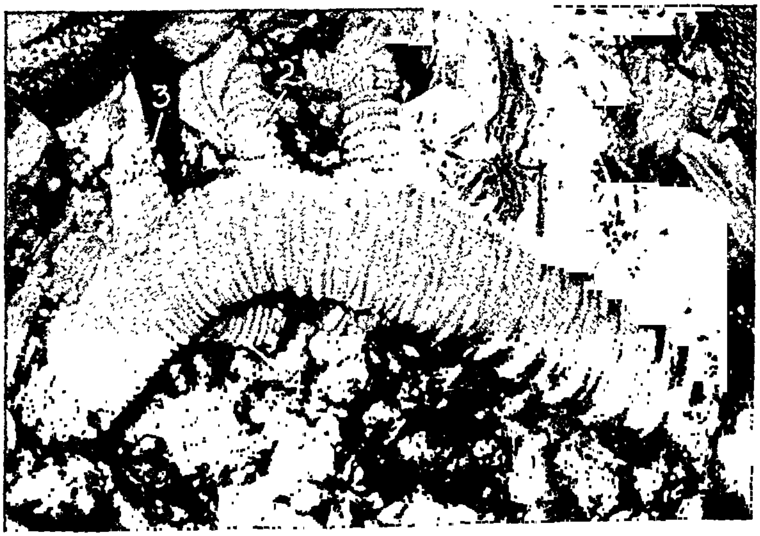
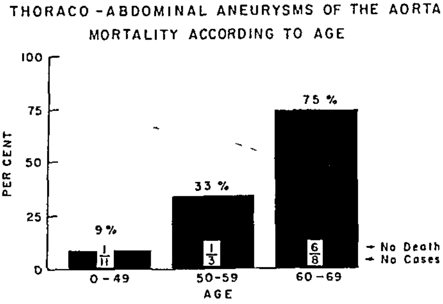


Fig. 12.—Photograph made at operation showing completed replacement of excised segment of thoracoabdominal aorta and aneurysm with Dacron tube, including branches to (*1*) celiac, (*2*) superior mesenteric, (*3*) left renal, and (*4*) right renal arteries.

as to the aorta above and below the aneurysm. After excising the aneurysm, end-to-end anastomoses of the right renal, superior mesenteric, and celiac arteries are performed in that order to the respective branches on the Dacron tube. After completion of each of these anastomoses, circulation is restored by releasing the occluding clamp on the corresponding branch of the Dacron tube. In this manner the period of ischemia to the right kidney should be less than 25 or 30 minutes and to the other arteries about 45 to 50 minutes which, according to our experience, is well within the safe period of tolerance of these organs to anoxia. The Dacron tube which has been serving as a temporary shunt is now converted into a permanent graft by suture closure of the thoracic aortic end just below the end-to-side anastomosis of the Dacron tube (Figs. 11 and 12).



Graph III.

In this series of 22 cases there were 8 operative deaths, 4 of which were caused by heart failure, 1 by renal failure, and 3 by the development of a bleeding syndrome. The significance of age upon operative mortality is well demonstrated by the fact that three fourths of the deaths occurred in patients over 60 years of age (Graph III). The results among the patients who survived operation have been highly gratifying. Follow-up observations extending over periods ranging up to 2½ years reveal maintenance of normal activities.

DISSECTING ANEURYSMS OF THE AORTA

This type of aneurysm represents one of the most serious forms of aortic disease and one of the most challenging problems in the application of surgical treatment, for several reasons. For one thing, the lesion is usually not well localized and often extends throughout the aorta. For another, the general condition of these patients is usually worse than that of others with aortic aneurysms owing presumably to the more acute development of the disease and the frequent association of hypertension and other manifestations of cardiovascular, renal, and respiratory disturbances. This is clearly reflected by studies of the natural course of the disease which have [illegible]rated its rapidly fatal termination in over 75 per cent of cases.[15]

The methods of surgical treatment for this disease have been reported in a previous publication[9] and have now been employed in 34 cases. The majority of these patients were in the fifth to seventh decades of life and all but 8 were males (Table IV). Moderate to severe hypertension was present in about 70 per cent of cases. Contrary to previous reports,[12, 13, 15] most of which have been based upon necropsy studies, indicating that the diseases usually involve the aortic arch, only 4 cases in our series were of this type. The dissecting process in all the others arose in the proximal segment of the descending thoracic aorta. This discrepancy in the location of the lesion in our surgical cases and in the studies of others based upon necropsy material may be explained by the fact that dissecting aneurysms arising in the ascending aorta are more likely to have a rapidly fatal course. On the other hand, lesions arising in the descending thoracic aorta tend to have a subacute course and thus to permit more time for diagnosis and treatment. In any event, this is a fortunate pathologic feature of the latter group of cases since, as indicated below, it permits application of a more effective form of surgical treatment.

In general, two types of surgical procedure were employed in this series of cases depending upon the nature of the lesion. Thus, in cases in which the dissecting process begins in the ascending aorta, the procedure consists in the creation of a re-entry passage into the true aortic lumen above with obliteration of the false passage below. This is accomplished by complete transection of the descending thoracic aorta between occluding clamps, excising a small segment from the inner wall above to produce re-entry of the outer lumen, approximation of the outer and inner layers below with a continuous suture, and then performance of an end-to-end anastomosis. As indicated previously, this procedure is obviously not curative; its essential objective is to produce re-entry of the false passage into the normal lumen as close to the point of origin of the dissection as may be feasible in order to diminish the likelihood of rupture above and to restore normal aortic circulation below. Among the 4 cases in this series in which this type of procedure was used, there were 2 deaths, 1 from rupture of the dissecting aneurysm into the pericardium and the other from heart failure.

For lesions arising in the descending thoracic aorta, usually just below the level of the left subclavian artery, a more curative type of procedure may be employed (Fig. 13). This is accomplished by excision of the segment involved in the origin of the dissecting process with graft replacement. In some cases in which the lesion is well localized to the descending thoracic aorta, complete resection of the dissecting aneurysm is possible. In other cases in which the dissecting process extends down into the abdominal aorta, the proximal portion involved in the origin of the dissection is excised, the false passage below is obliterated by suture of the inner and outer wall, and aortic continuity restored by graft replacement (Fig. 14). In the performance of this procedure, like that for fusiform aneurysms of the descending thoracic aorta, some method must be employed to combat the ischemic effects of temporary arrest of aortic circulation. Although hypothermia was originally used for this purpose, more recently we have preferred the method of controlled extracorporeal circulation, as described above, for resection of fusiform aneurysms of the descending thoracic aorta for similar reasons.

This latter method of surgical treatment for dissecting aneurysms was employed in 30 cases in this series with 8 deaths, 4 of which were caused by heart failure and coronary thrombosis, 2 by development of proximal dissection and rupture into the pericardium, 1 by pulmonary embolism, and 1 by ventricular fibrillation during hypothermia. Contrary to other forms of aortic aneurysms, age did not seem to play a significant role in the mortality in dissecting aneurysms (Table IV). Hypertension, however, was found to be highly significant in this regard since there were no deaths in patients considered to be normotensive (Table V).

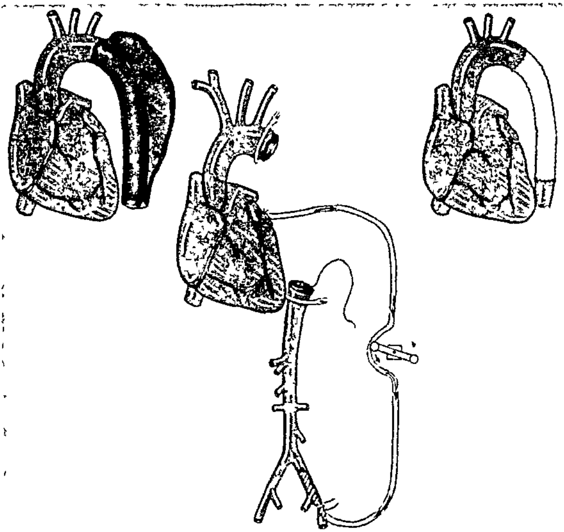


Fig. 13.—Drawing showing method of surgical treatment of dissecting aneurysms of aorta using controlled extracorporeal circulation to provide blood flow into aorta distal to site of application of occluding clamps. After excising segment of dissecting aneurysmal process above its origin, the false lumen in the distal end is obliterated by sewing outer and inner walls together with continuous suture. Anastomosis of graft to upper aortic opening is done by continuous suture with 4-0 arterial silk. Anastomosis of graft to lower opening in aorta with restoration of aortic continuity is then performed.

Table V. Dissecting Aneurysms of Thoracic Aorta
MORTALITY ACCORDING TO BLOOD PRESSURE

BLOOD PRESSURE	NO. CASES	DEATHS	
		NO. CASES	PER CENT
149/89 or less	10	0	0
150/90 or more	24	10	41
Total	34	10	

With few exceptions, the results obtained in the patients surviving operation have been highly gratifying. Follow-up observations extending up to 3½ years after operation reveal that most of the patients have been able to resume normal activities. There were 2 patients with residual partial paraplegia and 1 late death in this group (occurring about 7 months after operation) from severe uncontrolled hypertension. Subsequent aortographic studies in some cases revealed a relatively normal outline of the descending thoracic aorta (Fig. 14).

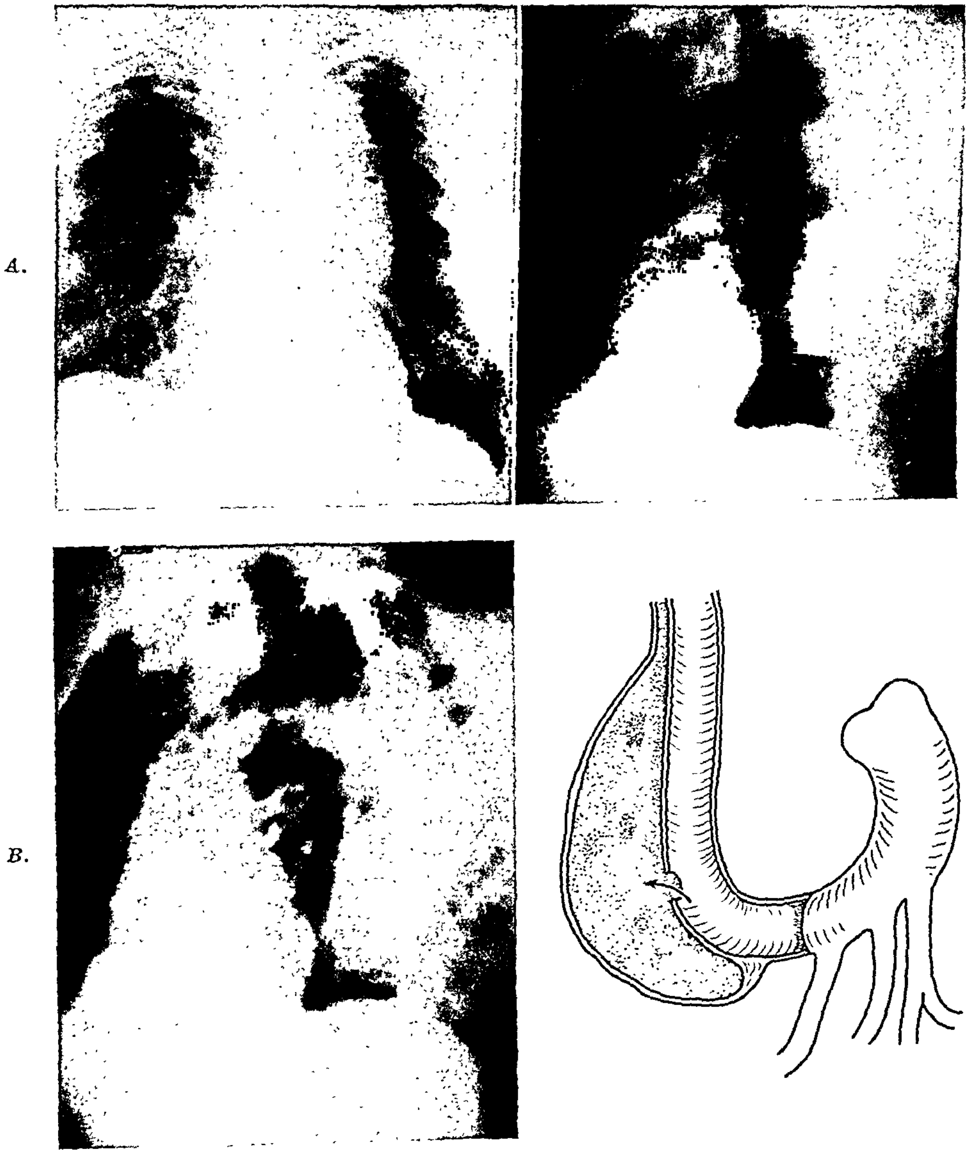


Fig. 14.—*A*, Roentgenograms of chest of patient with dissecting aneurysm of aorta showing, in anteroposterior projection, characteristic widening of supracardiac mediastinal shadow with relative radiolucency in its more peripheral part and, in lateral projection, extensive involvement of descending thoracic aorta.

B, Angiocardiogram of same patient showing characteristic double aortic lumen produced by relative difference in concentration of dye in true and false aortic lumens as depicted in diagram on right.

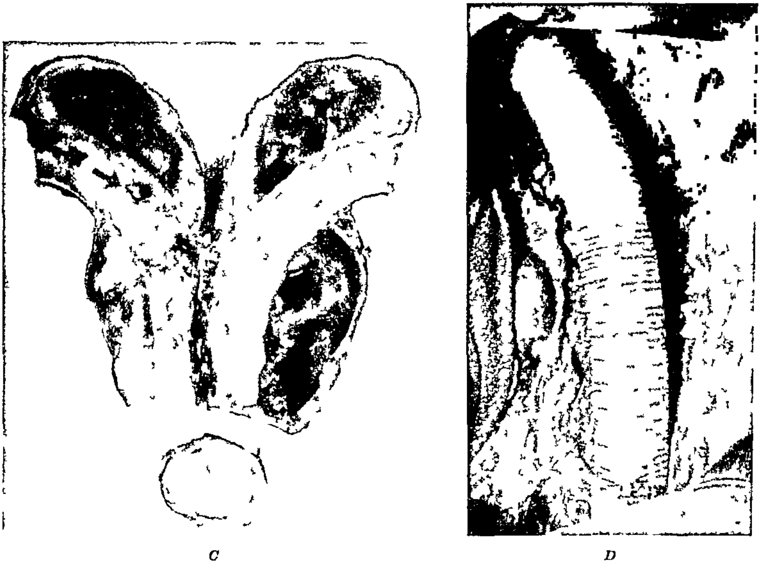


Fig 14 —Cont'd *C*, Photograph of sagittal section of resected segment of dissecting aneurysm in same patient showing gross pathologic features of lesion with arrow pointing to intimal tear through which true lumen communicated with false lumen Lower end of photograph shows cross sectional view of specimen demonstrating characteristic double barreled aorta with smaller true lumen and larger false lumen produced by dissection

D Photograph made at operation in same patient showing completed replacement of segment of aorta and dissecting aneurysm with Dacron graft

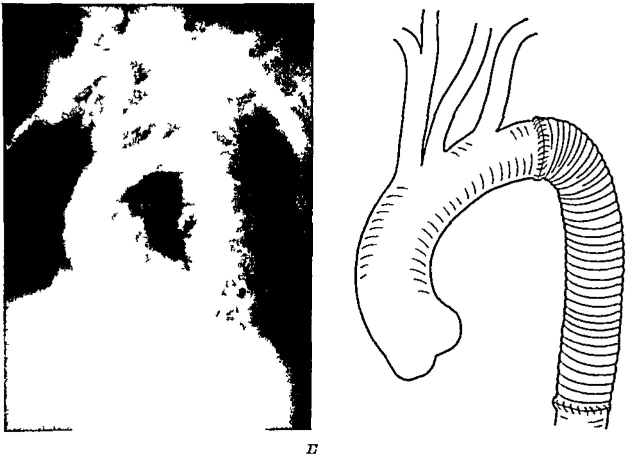


Fig 14 —Cont'd *E* Angiocardiogram in same patient made approximately 7 months after operation showing relatively normal outline of thoracic aorta. Patient has been completely relieved and has resumed normal activities

SUMMARY

1. Observations concerning methods and risk of operation are presented from an analysis of 179 cases of aneurysm of the thoracic aorta treated by resection. The cases are classified into 4 groups: (1) aneurysms of the descending thoracic aorta, (2) aneurysms of the aortic arch, (3) thoracoabdominal aneurysms, and (4) dissecting aneurysms.

2. Group 1, comprising 73 cases, represents the largest series and reflects the relative frequency of involvement of this segment. In the application of excisional therapy, the most important consideration stems from the necessity for temporary arrest of aortic circulation through the segment to be resected and the consequent effect of increased vascular resistance upon the heart and ischemic damage upon the spinal cord. Hypothermia was for some time the primary means used for prevention of neurological sequelae but was associated with certain disadvantages. Consequently, a method of controlled extracorporeal circulation was developed consisting of a pump-bypass in which oxygenated blood is removed from the left auricle and pumped into the aorta distal to the occluding clamps through a plastic cannula inserted upward into the left femoral artery. This method has been applied in the last 36 cases in this series and the mortality has been reduced from 27 per cent in the earlier series of 37 cases to 19 per cent in this more recent series. Owing to the fact that, in each series, 2 patients suffered some degree of neurological disturbance unexplainable by any variable in method or condition of the patient, the authors conclude that considerable variations exist in tolerance of the spinal cord to temporary aortic occlusion. Certain factors, such as age, etiology, hypertension, and pre-existing heart disease, are significant in the mortality rate. Follow-up observations extending for periods ranging from several months to over 5 years provide highly gratifying results, revealing with few exceptions complete relief of symptoms and resumption of normal activities.

3. Group 2, comprising 50 cases, represents the most serious form of aortic aneurysm because of the gravity of the disease and the inherent difficulties involved in excisional therapy. In certain sacciform aneurysms of the aortic arch, the procedure of tangential excision and aortorrhaphy may be preferable, but in fusiform aneurysms and in sacciform aneurysms in which the neck of the sac is relatively large, resection of the entire segment with graft replacement is necessary. Temporary arrest of aortic circulation at this level interrupts cerebral blood flow and can produce fatal ischemic damage to the central nervous system. Furthermore, a serious strain is thus placed upon the left ventricle causing the possibility of acute cardiac failure. Several methods may be employed to overcome these problems. For aneurysms involving the transverse arch of the distal portion of the ascending aorta, use of a temporary shunt is considered the procedure of choice. Recently, with the development of the crimped Dacron tube it has been possible to apply the bypass principle in a manner that permits its application both as a temporary and a permanent shunt. In cases in which the proximal portion of the ascending aorta is involved, cardiopulmonary bypass by means

of an artificial heart-lung apparatus is required. Factors bearing upon the operative risk include type and location of the aneurysm, age, and method of excisional therapy. The total mortality in this group was 56 per cent, but this figure must be evaluated against the extreme gravity of the natural course of this disease. Among surviving patients the results have been highly gratifying.

4. Aneurysms in Group 3 are significant particularly because they involve the principal vessels to the abdominal viscera, and excisional therapy is associated with danger of producing fatal ischemic damage to the liver, kidneys, and gastrointestinal tract as a consequence of temporary arrest of blood flow to these organs. In this group of 22 cases, syphilis was the predominant cause of the lesion. Several methods, including hypothermia, controlled extracorporeal circulation, and temporary shunts, have been employed to overcome the danger of damaging the sensitive abdominal organs. Recently another method has been developed through the use of the crimped, knitted Dacron tube which permits conversion of the temporary shunt into the permanent graft. In this series there were 8 operative deaths, 6 of which occurred in patients over 60 years of age. Results among patients who survived have been excellent, and follow-up observations extending over periods ranging up to 2½ years reveal maintenance of normal activity.

5. Among the 34 cases of dissecting aneurysm, 4 involved the aortic arch and the remainder arose in the proximal segment of the descending thoracic aorta. In cases in which the dissecting process begins in the ascending aorta, the procedure consists in the creation of a re-entry passage into the true aortic lumen above with obliteration of the false passage below. This procedure is obviously not curative, its objective is to diminish the likelihood of rupture above and to restore normal aortic circulation below. For lesions arising in the descending thoracic aorta a more curative type of procedure may be employed, consisting of excision of the segment involved in the origin of the dissecting process and replacement with graft. In cases in which the dissecting process is not well localized, the proximal portion is excised and the false passage below is obliterated by suture of the inner and outer wall. Aortic continuity is then restored by graft replacement. Thirty cases have been treated in this manner with 8 deaths. Age did not seem to be a significant factor in the mortality in dissecting aneurysms, but hypertension was highly significant, since there were no deaths in patients considered to be normotensive. Follow-up observations extending up to 3½ years reveal that most of the patients surviving operation have been able to resume normal activities.

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DISCUSSION

DR. JOHN W. STRIEDER, Brookline, Mass.—I rise only to emphasize a very small segment of Dr. DeBakey's magnificent presentation, namely, the pump bypass. As I mentioned this morning, Dr. James Dow and Dr. James Dickson at the Boston City Hospital Surgical Research Laboratory have been interested in this aspect of hemodynamics.

We have applied the pump which is similar to Dr. DeBakey's, except that it is operated by compressed air and permits one to have a bypass and/or a pump working electively, alternately.

In addition to its use for the excision of thoracic aneurysms, it may also be used in any situation where occlusion of the thoracic aorta is necessary.

We have used it, therefore, in a patient who was severely ill, the result of aortic regurgitation, where we contemplated inserting a Hufnagel valve.

This slide shows the pressures which were taken above and below the point of occlusion through the axillary artery and the femoral artery. Catheters have been passed through both these vessels a suitable distance. One can then see graphically that when the bypass is open with the pump not working, the pressures above and below the point of occlusion of the aorta show a definite differential with the pressures below the point of occlusion falling off, but remaining at approximately 60 mm. Hg systolic. When the bypass is clamped and the pump started, however, the pressure in the distal aorta remains at a satisfactory level, approximately that of the pressure in the proximal aorta. This permits a leisurely approach to the operation described by Hufnagel.

As I mentioned before, it was used in one such patient and was highly successful technically, although subsequently the patient died for reasons which were not discernible at autopsy and apparently bore no relation to the method.

EXPERIENCES WITH THE DAVILA-GLOVER PURSE-STRING SUTURE IN THE CORRECTION OF MITRAL INSUFFICIENCY: A CRITICAL APPRAISAL

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During the Thirty-fifth Annual Meeting of the American Association for Thoracic Surgery, Davila and Glover and their associates[1] described a method of accomplishing circumferential suture of the mitral ring for the correction of valvular insufficiency. That presentation included their experiences during the perfection of the technique in the experimental laboratory and the use of the operation in the surgical management of 7 patients whose valvular disease was characterized by predominant mitral insufficiency. Although the mortality rate was high in this preliminary report, the authors felt that the results in the surviving patients were most encouraging.

The essentials of the procedure as described by Davila and co-workers consist of placing the suture medially by approaching the posterior aspect of the heart and introducing the needle at a point just to the left of the posterior descending coronary artery and immediately beneath the coronary sinus and distal circumflex coronary artery. The needle then was passed ventrally into the base of the interatrial septum and thence into the right atrium, entering this chamber at a point just ventrad to the ostium of the coronary sinus, then advanced adjacent to the right side of the septum, piercing the anterior right atrial wall at its junction with the anterior base of the septum. At this point, the needle and suture emerged into the transverse sinus and the segment of the suture which was to lie in the transverse sinus was encased in a pericardial sleeve, 4 cm. in length. A tunnel was then made anteriorly beneath the circumflex coronary and great cardiac vein at a point about 1 cm. lateral to the anterior descending coronary. The segment of suture which had been covered by pericardium was then drawn back into the transverse sinus by traction on the posterior "tail." The anterior "tail" was then passed beneath the circumflex coronary through the previously prepared tunnel. The posterior "tail" of the suture was then threaded on a large curved needle and stitched anterolaterally

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Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958 into the atrioventricular groove, underpassing the lateral branches of the circumflex coronary so that it finally lay just beneath the circumflex bundle. The two tails were then approximated about 1 cm. to the left of the anterior descending coronary and immediately below the circumflex coronary where they were tied in a double square knot. As this knot is tied, the operator maintains a tactile vigil over the effect on the valvular regurgitation by means of the exploring finger which remains within the left atrium by way of its appendage. This finger also serves as a means to prevent the creation of stenosis of the valvular orifice during the tying of the knot in the purse-string suture and has the equally great responsibility of monitoring the placement of the purse-string suture to ensure against the insertion of any portion of the suture within the left atrial chamber.

It is apparent to all interested observers that there is a great need for a method which will safely and effectively control mitral insufficiency when it is of major proportions. Our purpose in this communication is to present our experiences and results with the use of the Davila-Glover circumferential suture of the mitral ring as a means of attempting to control *predominant mitral* regurgitation in 30 patients.

METHODS

Patients were selected for surgical correction of mitral insufficiency on the basis of clinical evaluation and supporting data obtained by means of simultaneous right and left heart catheterization and by means of the injection of Evans blue dye into the left ventricle followed by immediate recovery of the medium from the left atrium.

In the area of clinical evaluation of patients, the measures adopted did not differ from those employed generally. The presence of an apical systolic murmur has been the cardinal method of spotting patients suspected of having mitral insufficiency. Some of these patients displayed qualities inherent in their murmurs which are commonly accepted as indicative of a significant degree of valvular incompetence (i.e., loudness, transmission to the axillary area, decreased intensity of the mitral first sound).

Further documentation includes evidence of left ventricular enlargement by means of electrocardiography, roentgenography and fluoroscopy. Additionally, evidence of left atrial enlargement was sought by the same avenues of study. The presence or absence of atrial fibrillation was demonstrated in all instances.

Each patient in this study was severely disabled by predominant mitral insufficiency.

The supporting data which have been obtained by means of combined right and left heart catheterization are available for all save 2 patients. The criteria obtained by these measures include the appearance of a tall regurgitant pulse in the left atrium (V wave exceeding the height of the C wave by 10 mm. Hg or more[2, 3]).

More consistent evidence of mitral regurgitation is obtainable by means of the injection of Evans blue dye into the left ventricle during left heart catheterization.[4] In the presence of mitral regurgitation, immediate recovery of the medium from within the left atrium can be expected.

Left heart catheterization was performed in the prone position using the right paravertebral approach. Usually, right heart catheterization was done in a similar manner through a second needle.[2, 3]

The passage of a catheter into the left ventricle permitted measurement of any pressure gradients across the mitral and aortic valves. The recording of left atrial pulse pressure usually revealed the degree of mitral regurgitation accurately[2, 3] as long as the mean left atrium pressure was above 20 mm. Hg. At lower mean atrial pressures, the regurgitant pulse could frequently be evoked by exercise.

More recently, however, a simple dye injection technique has been more satisfactory for evaluating valve competency. In brief, the technique consists of injecting dye into the left ventricle via a catheter while aspirating from a separate left atrial needle. This is compared to a similar injection into the left atrium via the catheter while aspirating from the separate needle. As can be seen from Tables I and II, it is apparent that the test does not overestimate the degree of insufficiency.

The patients selected for surgical intervention were managed by the application of the Davila-Glover purse-string procedure as described by them, using the Davilla needle designed for this purpose.

The postoperative evaluation of results have been based upon the same triad which was employed in the preoperative selection of patients, namely, clinical evaluation, simultaneously combined right and left heart catheterization, and the injection of Evans blue dye into the left ventricle with subsequent recovery from the left atrium. An altogether too limited autopsy experience has also been included.

RESULTS

There were 13 hospital deaths (Table I). The majority of these (8) resulted from uncontrollable ventricular fibrillation at the time of surgery. Three patients died within 24 hours after completion of operation. One patient died 4 weeks after surgery as a result of subacute bacterial endocarditis due to hemolytic *Staphylococcus aureus* and the remaining patient died 2 months after operation of uncontrollable congestive heart failure. It has been apparent that this surgical procedure carries a very substantial risk for patients in the advanced categories which were selected. In an effort to overcome the problem of ventricular fibrillation at surgery, partial cardiac bypass was employed during the introduction of the purse-string suture in 3 patients. The first of these efforts appeared to be very successful and a patient having profoundly severe mitral insufficiency was thus operated upon with an excellent early clinical result. However, the signs of the regurgitatic

TABLE I. DATA ON DEAD PATIENTS*

PATIENT	AGE	NYHA CLASS	CATHETERIZATION RESULTS								PREOPERATIVE DIAGNOSIS	SURGICAL OBSERVATIONS PURSE STRING		THERAPEUTIC RESULT
			RA	RV	PA	LA	LV	AO	BLUE DYE	V-C		PREOP.	POSTOP.	
H. R.	50	IV	(19)	72/12-16	72/38	(21)	108/18-20	108/66	N.D.	49	4+ M.I.	4+ M.I.	0 M.I.	Hospital death
E. G.	48	III	(7)	92/3-8		(8-13)	130/0-10	110/78	N.D.	24	4+ M.I.	4+ M.I.	2+ M.I.	Hospital death
I. F.	20	III		44/4-7	44/30	(12)	110/4-7	115/84	N.D.	6	2+ M.I.	4+ M.I. 1+ M.S.	0 M.I.	Hospital death
M. C.	25	IV		80/0		(12)	115/0-2	115/86	3+	10	3+ M.I.	4+ M.I.	0 M.I.	Hospital death
E. K.	35	IV				30/14		128/94	N.D.	8	3+ M.I.	4+ M.I.	0 M.I.	Hospital death
M. M.	23	III	(4)	25/2-4		(10)	100/	100/63	3+	3	3+ M.I.	4+ M.I.	0 M.I.	Hospital death
G. B.	33	IV	(17)	58/13-17		(22)	114/14-29	111/69	3+	5	3+ M.I.	4+ M.I.	0 M.I.	Hospital death
M. C.	34	IV	(10)	22/0-4		(8)	112/4-7	112/68	3+	4	3+ M.I.	3+ M.I.	0	Hospital death Subacute bact. endocarditis
F. K.	30	III				(9)	105/0-5	105/60	N.D.	14	4+ M.I.	4+ M.I.	2+ M.I.	Hospital death
J. M.	49	IV	(9)	45/6-9	45/20	(19)	100/5-11	100/56	N.D.	9	3+ M.I. Trace M.S.	4+ M.I.	2+ M.I.	Hospital death
†C. J.	40	III									M.S.	4+ M.I.		Hospital death
W. P.	18	IV	(13)			(18-35)	116/11-14	115/75	N.D.	10	4+ M.I.	4+ M.I. A.I.	0 M.I.	Hospital death
L. J.	42	IV	(14)	55/9-16		(38)			N.D.	6	2+ M.I.	4+ M.I.	0 M.I.	Hospital death
‡T. M.	25	III	Pre-op.	46/1	76/46	(26)	72/11	72/60	3+	6	3+ M.I.	3+ M.I., 2+ M.S.	1+ M.I., 1+ M.S.	Late death
		III	Post-op.		78/50	(20)	88/2-6	90/56	3+	0	3+ M.I.			
W. M.	26	III				(9)	120/7-10	120/60	3+	3	3+ M.I.	3+ M.I.	1+ M.I.	Late death
‡A. N.	32	IV	(15)	75/11-15		(24)	105/10-14	105/63	N. D.	21	4+ M.I.	4+ M.I.	1+ M.I.	Late death
J. B.	33	IV	(15)	58/11-18		(30)	93/0-4	90/63	3+	6	3 M.I.	3+ M.I.	1+ M.I.	Late death
B. D.	34	IV	(13)	103/7-11		(19)	103/5-8	103/83		9	3 M.I.	4+ M.I.	0 M.I.	Late death
§C. R.	23	III									M.S.	3+ M.I.	1+ M.I.	Late death

N. D. = Test not done.

*Composite of data on all patients who have died. Thirteen hospital deaths and 6 late deaths have been included.

†Not tested preoperatively.

‡Purse string suture cut-through.

§Incomplete left heart catheterization preoperatively.

months and the patient died 3 months later of congestive heart failure. Autopsy disclosed cut through of the purse string (Fig. I). The remaining 2 patients operated upon with the assistance of partial cardiac bypass died of uncontrollable ventricular fibrillation during surgery.

There have been 6 additional deaths, each occurring after the patient was discharged from the hospital after having progressed through apparently successful surgery and uncomplicated convalescence (Table I). Three of these deaths were sudden and fairly early after surgery, each occurred at home, and autopsies were not obtained. The 3 remaining late deaths were preceded by evidence of recurrence of mitral insufficiency and somewhat prolonged congestive heart failure. Autopsy in these 3 patients disclosed evidence of cut through of the purse string suture.

The result of the application of the purse string as determined by the surgeon at the time of operation has been impressive. Indeed, in almost every instance the palpable regurgitant jet was greatly reduced as measured by the tactile sense of the operator's intra atrial finger. These observations have been in complete agreement with those published by Davila and Glover.

An observation of major importance was that the degree of mitral regurgitation varied markedly depending upon the work of the left ventricle. When ever systemic arterial pressure was low, the improved cardiac output resulting from the initial tightening of the purse string raised the systemic pressure. As this happened, the tactile evidence of regurgitation increased, requiring further tightening of the suture. These observations would seem to be of importance in open heart surgery for mitral insufficiency, since visual estimation of the regurgitant flow, when the left ventricle is pumping very little blood, may be incorrect.

The disappointing experience of having the apical systolic murmur recur within a few days to a few weeks, or months in most patients is one which can not be forgotten. Among the survivors who were followed for a reasonable period of time, this event occurred in 7 of 11 patients. Following this auscultatory evidence of recurrence of mitral insufficiency, there ensued clinical evidence of loss of symptomatic gains.

In an effort to obtain objective information concerning the status of the survivors, postoperative left heart catheterization and blue dye injection was carried out on 10 of the 11 surviving patients (Table II). These tests were done more than 6 months after surgery and the data secured disclose that 7 patients now have mitral insufficiency of degrees equaling those demonstrated prior to operation. There are 4 patients in whom there remains no demonstrable regurgitation but 2 of these have evidence of mitral stenosis. A single patient who was retested 10 days after undergoing surgery was found to have had objective evidence of recurrence of severe valvular insufficiency. This has been suspected clinically as a result of recurrence of an apical systolic murmur 6 days after surgery. This patient has since died in chronic uncontrollable congestive failure and autopsy confirmed the recurrence of mitral regurgitation.

TABLE II. D[illegible] LIVING PATIENTS*

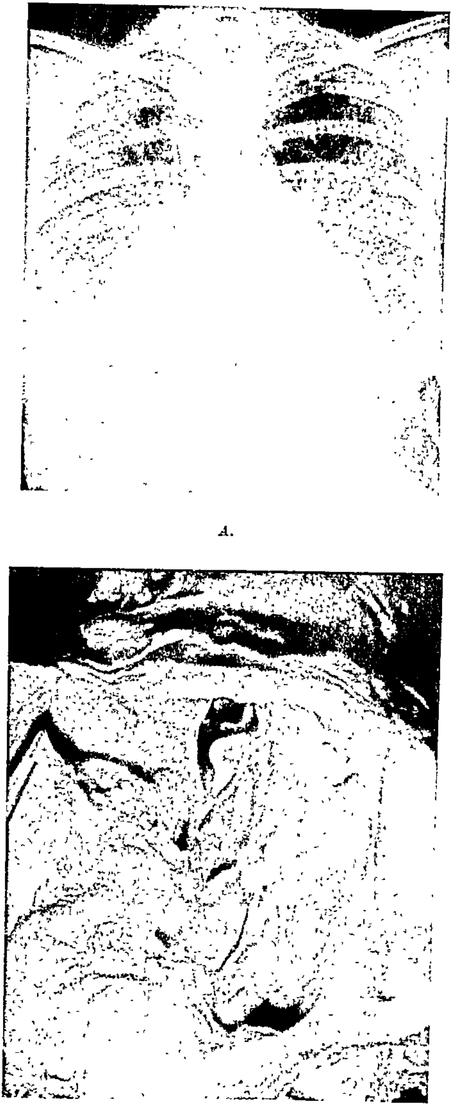
PATIENT	AGE	NYHA CLASS	CATHETERIZATION RESULTS								PREOP. DIAGNOSIS	SURGICAL OBSERVATIONS PURSE STRING		THERAPEUTIC RESULT
			RA	RV	PA	LA	LV	AO	BLUE DYE	V-C MM. HG		PREOP.	POSTOP.	
M. T.	40	III	(3)	26/4-5	26/15	(9)	109/2-4	109/72	2+	0	2+ M.I. 2+ M.S.	2+ M.I. 2+ M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	42	II	(4)	26/2-4	26/16	(13)	140/6-8	140/107	1-2+	5	1-2+ M.I. 2+ M.S.			
M. B.	33	III	(8)	35/6-11		(13)	104/7-11	102/68	3+	0	3+ M.I.	4+ M.I.	1+ M.I.	Symptomatically unimproved
	34	III	(9)	40/1-8	39/19	(20)	120/2-9	111/79	3+					
D. C.	31	II	(10)	62/6-11		(24)			N.D.	6	3+ M.S. 2+ M.I.	3+ M.I. 2+ M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	32	II	(4)	28/2-3		(10)	93/2-3	93/70	0	3	2+ M.S.			
C. B.	47	III				15-19	120/8-18	120/68	2+	2		3+ M.I.	0 M.I.	Symptomatically worse
	48	IV				(20)	135/7-10	135/74	3+	6	1+ M.S.			
C. A.	35	III	(10)	36/6-10		(18)	111/5-9	100/78	3+	3		3+ M.I.	0 M.I.	Symptomatically worse
	36	IV	(13)	45/7-12		(22)	109/4-13	112/92	3+	6				
W. M.	28	III	3-5	50/0-4		(25)	83/1-3	88/67	3+	5	3+ M.I. M.S.	4+ M.I. 1+ M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	29	III	(7)	40/2-8		(22)	104/3-6	104/80	0	4	3+ M.S.			
M. F.	24	IV		38/8-10		(28)	88/6-8	76/10	3+	5	3+ M.I. 3+ M.S. 1+ A.S.	3+ M.I., M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	25	II	(6)	32/1-6	28/15	(20)	107/0-6	105/84	3+	6	1+ M.S.			
L. J.	43	III	(9-14)	66/12	66/26	90/13	122/7-13	133/66	N.D.	50	4+ M.I.	4+ M.I.	0 M.I.	Symptomatically worse
	44	III	(9)	80/7-14	80/28	(24)		120/76	N.D.	35	4+ M.I.			
J. J.	40	III	(14)	73/12		(33)	114/0-18	115/85	2+	8		3+ M.I.	0 M.I.	Symptomatically improved
	41	III	(12)	85/6-12		(29)	165/10-14		0	0	4+ M.S.			
†C. K.											M.S.	3+ M.I. 1+ M.S.	1+ M.I.	Symptomatically unimproved
	34	II	(6)	49/5-13	49/28	(22)	106/2-10	88/74	0	2	3+ M.S. A.S.			
‡R. E.	27	III	(4)	28/0-2	19/11	(7)	128/4-8	107/60	3+	1	3+ M.I. A.S.	3+ M.I. A.S.	0 M.I.	Symptomatically unimproved

N. D. = Test not done.

*Composite of data on 11 surviving patients. The information includes that of pain before surgery as well as operative and postoperative findings.

†No preoperative catheterization.

‡No postoperative catheterization (LHC).



A.

B.

Fig. 1.—*A*, Chest film taken prior to surgery discloses large heart and right pleural effusion due to congestive failure. *B*, Photograph of heart made at autopsy 9 months after surgery. The purse-string suture can be seen to have cut through into left atrium just above mitral valve.

TABLE II. D[illegible]N LIVING PATIENTS*

PATIENT	AGE	NYHA CLASS	CATHETERIZATION RESULTS								SURGICAL OBSERVATIONS PURSE STRING			THERAPEUTIC RESULT
			RA	RV	PA	LA	LV	AO	BLUE DYE	V-C MM. HG	PREOP. DIAGNOSIS	PREOP.	POSTOP.	
M. T.	40	III	(3)	26/4-5	26/15	(9)	109/2-4	109/72	2+	0	2+ M.I. 2+ M.S.	2+ M.I. 2+ M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	42	II	(4)	26/2-4	26/16	(13)	140/6-8	140/107	1-2+	5	1-2+ M.I. 2+ M.S.			
M. B.	33	III	(8)	35/6-11		(13)	104/7-11	102/68	3+	0	3+ M.I.	4+ M.I.	1+ M.I.	Symptomatically unimproved
	34	III	(9)	40/1-8	39/19	(20)	120/2-9	111/79	3+					
D. C.	31	II	(10)	62/6-11		(24)			N.D.	6	3+ M.S. 2+ M.I.	3+ M.I. 2+ M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	32	II	(4)	28/2-3		(10)	93/2-3	93/70	0	3	2+ M.S.			
C. B.	47	III				15-19	120/8-18	120/68	2+	2		3+ M.I.	0 M.I.	Symptomatically worse
	48	IV				(20)	135/7-10	135/74	3+	6	1+ M.S.			
C. A.	35	III	(10)	36/6-10		(18)	111/5-9	100/78	3+	3		3+ M.I.	0 M.I.	Symptomatically worse
	36	IV	(13)	45/7-12		(22)	109/4-13	112/92	3+	6				
W. M.	28	III	3-5	50/0-4		(25)	83/1-3	88/67	3+	5	3+ M.I. M.S.	4+ M.I. 1+ M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	29	III	(7)	40/2-8		(22)	104/3-6	104/80	0	4	3+ M.S.			
M. F.	24	IV		38/8-10		(28)	88/6-8	76/10	3+	5	3+ M.I. 3+ M.S. 1+ A.S.	3+ M.I., M.S.	0 M.I. 1+ M.S.	Symptomatically improved
	25	II	(6)	32/1-6	28/15	(20)	107/0-6	105/84	3+	6	1+ M.S.			
L. J.	43	III	(9-14)	66/12	66/26	90/13	122/7-13	133/66	N.D.	30	4+ M.I.	4+ M.I.	0 M.I.	Symptomatically worse
	44	III	(9)	80/7-14	80/28	(24)		120/76	N.D.	35	4+ M.I.			
J. J.	40	III	(14)	73/12		(33)	114/0-18	115/85	2+	8		3+ M.I.	0 M.I.	Symptomatically improved
	41	III	(12)	85/6-12		(29)	165/10-14		0	0	4+ M.S.			
†C. K.											M.S.	3+ M.I. 1+ M.S.	1+ M.I.	Symptomatically unimproved
	34	II	(6)	49/5-13	49/28	(22)	106/2-10	88/74	0	2	3+ M.S. A.S.			
‡R. E.	27	III	(4)	28/0-2	19/11	(7)	128/4-8	107/60	3+	1	3+ M.I. A.S.	3+ M.I. A.S.	0 M.I.	Symptomatically unimproved

N. D. = Test not done.

*Composite of data on 11 surviving patients. The information includes that of pain before surgery as well as operative and postoperative findings.

†No preoperative catheterization.

‡No postoperative catheterization (LHC).

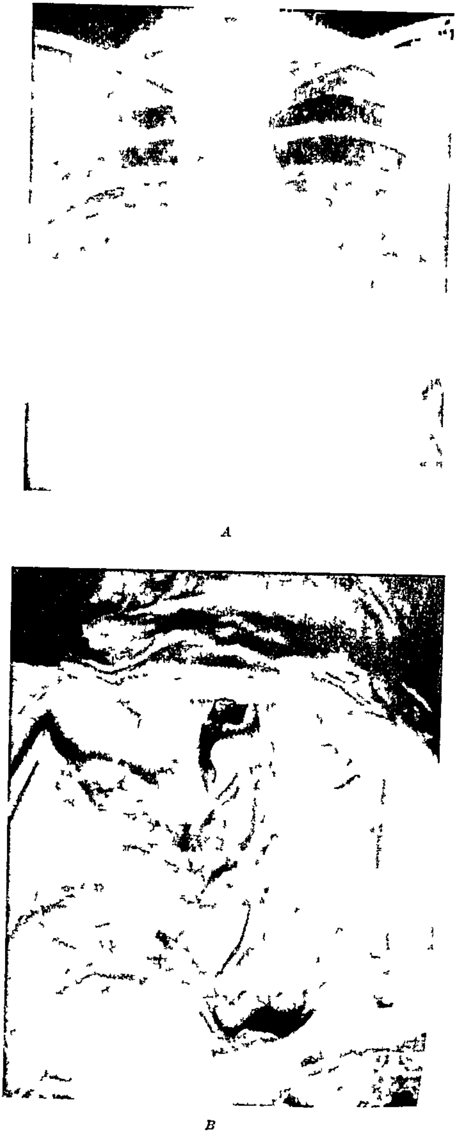


Fig. 1.—*A*, Chest film taken prior to surgery discloses large heart and right pleural effusion due to congestive failure. *B*, Photograph of heart made at autopsy 9 [illegible] surgery. The purse string suture can be seen to have cut through into left [illegible] mitral valve.

As further evidence of recurrence of valvular insufficiency we can present the autopsy findings of only 3 patients who have died 3 or more months after surgery. In 2 instances, the purse string had cut through the atrial wall and, in part, lay free in the atrial chamber just above the mitral leaflets (Fig. 1). In the third such instance, it was quite apparent that the purse string had cut through sufficiently to lose the effect although the suture had not entered the atrial cavity at any point.

SUMMARY

1. The circumferential purse-string suture described by Davila and Glover effectively controls mitral regurgitation at the time of application.

2. There has been a high incidence of recurrence of valvular incompetence, chiefly the result of cut-through of the purse-string suture.

3. A high mortality rate has been experienced.

4. There is evidence which indicates that we have produced a measureable degree of mitral stenosis in 2 patients both of whom have maintained control of a previous insufficiency.

5. Observations made during the surgery performed for mitral insufficiency indicate that the degree of valvular regurgitation may be underestimated under the conditions which prevail during open heart surgery.

6. The evaluation of surgical results of surgery for mitral insufficiency requires the utmost objectivity at our disposal. We feel that left heart catheterization studies, of the scope employed in this study, are mandatory.

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DISCUSSION

DR. J. C. DAVILA, Philadelphia, Pa.—Every year at this meeting someone invariably asks, "Are you still doing this operation?" and we have answered, "Yes, we are." I am of course very disappointed by the results which Dr. Kent, Dr. Neville, and Dr. Fisher have reported. This is a procedure which is technically exacting, and about which perhaps some details have not been fully emphasized or sufficiently clearly elucidated in our published reports. I would like to point out one feature which Dr. Neville and I discussed some days ago.

(slide) If the suture is placed in a manner which catches a band of epicardium in a loop and it is tied, a very disagreeable puckering is produced. Not only is this undesirable from the standpoint of hampering coronary arteries, but it is undesirable because the suture is unable to slide through after final tying to glide into the apex of the A-V groove This may appear to be a minor point but it is very important In placing this portion of the suture it is necessary to come out with the suture and return through the same puncture in order that the suture lie entirely in fat When it is tied it then glides into the proper position This will eliminate to a very large degree, although not completely, the loosening of the suture (slide) This is shown to point out the repetition of the loop back through the same orifice

We have had only 1 case in which the suture was misplaced into the cardiac lumen, it occurred very early in our series We have not had the suture cut through in any other patient or, in fact, in a large number of dogs in a period of 3 years of observation

This slide simply shows the tracing of a patient whom Dr Morrow catheterized in Washington, 1 month before surgery, 1 month after surgery, and 9 months after surgery

(slide) This is the longest follow up we have studied—a patient who was catheterized at 6 months and at 24 months postoperatively You will note the left atrial pressure remains low, the pulmonary pressure remains low, the output doubles and remains that way, the pulmonary resistance is low The heart size (by cardiothoracic ratio) remains small

(slide) I wish to point out what has happened in our experience during the past 4 years We have operated on 61 patients and I have divided them into three groups 20 patients, 20 patients, and 21 patients, progressively In the first 20 patients, there were six operative deaths, eight late deaths, and 6 are living, the next 20, six operative deaths, four late deaths, 10 are living In the last 21, there were six operative deaths, one late death, and 14 are living This represents not necessarily technical improvement but better selection of patients, and this is the crux in the success of this operation It is not unlike the catastrophe which Dr Potts referred to When we operate on a patient in a far advanced stage of disease, that patient is going to die whether we have corrected the insufficiency or not

This is another aspect of the breakdown Half of our patients roughly, 29, were preoperatively in medically intractable failure, 32 were in various stages of congestive failure but were not intractable preoperatively Of the 29 in intractable states only 4 are living and only 2 of those are improved Of the 32 in varying degrees of failure, 26 are living and 26 are improved

We have not studied by recatheterization a sufficient number of patients completely to show comparable data before and after surgery, nor do we have time now to discuss that in more detail, but those we have studied have shown favorable results

DR LOUIS H BOSHER, Richmond, Va —My experience with this operative procedure is very limited, but so unsatisfactory that I wish also to support Dr Kent's observation regarding it

We have operated upon 6 patients, 2 of whom were operative deaths, that is, occurring early postoperative There were 2 patients who died later, 1 six weeks and 1 five months later, and I would like to show two slides of the specimens

(slide) You will see that in this patient the suture has cut through 5 weeks after surgery There was clinical evidence of recurrence of mitral insufficiency I might say that this suture was not enclosed in a pericardial tube as recommended by the authors of the procedure

(slide) The second patient died 5 months later, the suture was enclosed in a plastic tube between the circumflex artery and the point of emergence in the transverse sinus The suture did not cut through at this site but cut through elsewhere along the annulus It is our opinion that if the annulus is markedly dilated, which is the situation in most of the patients, if you exert enough tension to eliminate the mitral insufficiency then almost certainly the suture will eventually cut through We do have 2 patients alive who have had this procedure They are somewhat improved One of these patients exhibited evidence of elimination of mitral insufficiency for some m[illegible] bu[illegible] [illegible] gradually returned and at the present time he has lost ground

DR. J. NEVILLE (Closing).—In fairness to Dr. Davila, I would like to say that the technique which we used in placing the purse string was that originally described. It did not include the modification presented here. Whether this would influence the results which we have obtained I am not able to say at the present time.

We were quite impressed at the time of surgery by the ability of this operative procedure to control regurgitation. Despite our rather high operative mortality from ventricular fibrillation, we were rather reluctant to discontinue the procedure because it apparently offered some hope to a group of desperately sick patients.

An example of one of these patients is exemplified by this x-ray (slide). This patient required 3 months of hospitalization and intensive medical management to be brought into a reasonable cardiac compensation. Because of our prior experience with ventricular fibrillation in this type patient, she was operated upon using a pump-oxygenator by diverting only part of the cardiac output. With the blood continuing to return to the left atrium we were able to determine the degree of regurgitation more efficiently. The patient did survive the operative procedure despite a bout of fibrillation and a dramatic result ensued. Whereas previously she had been completely bedridden, within 3 months she was doing all of her housework. In addition, due to inadequate advice to the local physician, she was on a regular diet and off digitalis. Approximately 6 months after surgery, symptoms recurred and a progressive downhill course ensued. She was hospitalized and an autopsy fortunately was obtained.

I think this slide speaks for itself (purse string lying free in atrial cavity over one-half circumference).

There is one observation Dr. Kent made which I should like to amplify briefly. It was impressive at the time of placement of the purse-string suture to observe the relationship between the degree of regurgitation and the arterial blood pressure. Usually the blood pressure was quite low initially. As the purse string was tightened, the arterial blood pressure rose and the regurgitation would reappear or increase. Further tightening of the purse string would control the regurgitation but, as the arterial pressure rose further, the same phenomenon would take place. It was not until a normal systemic pressure had been obtained that we would be sure of the control of the regurgitation. I think this observation is pertinent to open operative correction of mitral regurgitation, for when the left ventricle is not completely filled, so that the intraventricular pressure does not reach normal levels, the degree of regurgitation may be very difficult to estimate. A false sense of security may result from merely the visual correction of the regurgitation.

TECHNICAL CONSIDERATIONS IN DECORTICATION FOR THE PLEURAL COMPLICATIONS OF PULMONARY TUBERCULOSIS

Paul C. Samson, M.D., Duane L. Merrill, M.D. (by invitation), David J. Dugan, M.D., Oakland, Calif., E. J. Shabart, M.D. (by invitation) Livermore, Calif., James Yee, M.D. (by invitation), Oakland Calif., and Louis M. Barber, M.D. (by invitation), French Camp, Calif.

THE MODERN era of decortication for pleural complications in tuberculosis may be said properly to date from the end of World War II. During the war, the pathology of organizing hemothorax was finally settled. Many thoracic surgeons returned to civilian life with a considerable background experience in decortication for organizing hemothorax and post traumatic empyema. In refocusing their attention on peacetime pursuits, it was only natural that renewed interest developed in treating the unexpandable lung in tuberculosis as well as in tuberculous empyema.

Another advance of the greatest importance likewise soon appeared: the development of specific chemotherapy for tuberculosis. As this discovery related to decortication, it meant that the prevention of invasive tuberculous infection made surgery safe in a contaminated field, thus enhancing the value of operative procedures already proved technically adequate.[1]

During the past decade a number of important contributory articles have appeared on decortication in tuberculosis.[2-11]

PATHOLOGY

While it was originally considered that the fibroblastic reaction in the pleural cavity (and the eventual development of a "peel") was in some way a specific response to the presence of blood, it became rapidly apparent that any insult to the pleural cavity would result in the same reaction. Air, pyogenic infection, specific effusions, viral effusions, chyle, and even neoplasm will elicit the same primary nonspecific response by the pleura: fibrin deposition on the exposed pleural surfaces, early fibroblastic and angioblastic proliferation, formation of a complete membranous envelope having both visceral and parietal components and containing air or liquid debris. Thick or thin, the fully developed membrane or peel in each case is composed of adult tissue relatively poor both in blood supply and nuclei.

From the Thoracic Surgical Services of Highland Alameda County Hospital, muel Merritt Hospital, Peralta Hospital, Oakland, Calif., The Veterans Administration Hospitals, Livermore and Oakland, Calif., The San Joaquin General Hospital, French Camp, Calif.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

The microscopic evidence of tuberculous infection is most frequently found along the inner or closed surface of the envelope away from the pleurae (Fig. 1). It is seldom seen invading the membrane or peel itself unless the tuberculosis is an extension outward from a pulmonary lesion. Therefore, the cleavage line between peel and pleura can nearly always be developed without disturbing the tuberculous infection within the envelope. In addition, adequate chemotherapy destroys the microscopic picture of specificity in an empyema in the majority of instances coincident with the disappearance of tubercle bacilli from the fluid (Fig. 2). This is a further and very important safety factor during and following surgery.

MATERIAL

During the 10-year period ending early in 1957, a total of 237 significant decortications were performed on the Thoracic Surgical Services of the indicated institutions. Nearly all of these were performed by the authors, except at Highland-Alameda County Hospital where at least half were done by former residents.

Of the 237 operations, decortication was the main procedure in 104, and an incidental but important adjunct to resection in 133.

Among the 104 patients, 39 operations were performed for unexpanded lung due to pneumothorax or pleural effusion; 6 for "false re-expansion"; 7 for pyogenic, 35 for pure tuberculosis, and 17 for mixed infection empyema. In this group, there were additional resections in 30 cases (4 of these with concomitant thoracoplasty) and *adjunctive* tailoring thoracoplasties (both concomitant and postdecortication in another 13 cases).

Among the 133 patients, no thoracoplasty was performed in 60 per cent; a preresection thoracoplasty was performed in 18 per cent, a concomitant thoracoplasty in 13 per cent, and a postresection thoracoplasty in 9 per cent.

INDICATIONS

The rationale of decortication in tuberculosis needs but brief comment. Obliteration of an intrapleural space, removal of infection, re-expansion of lung, and hemithoracic restitution with as near normal mobility as possible are the desiderata.

The indications are various: the unexpandable lung, following pneumothorax therapy or primary pleural effusion; the "false re-expansion"; intrapleural empyema, pyogenic, pure tuberculous, or mixed; and finally the incidental decortication necessary with many parenchymal resections for better re-expansion of remaining lung tissue.

There are, in addition, certain miscellaneous indications for decortication because of postresection complications. These arise rarely but are important in the individual case. Realization that a type of decortication is possible may induce the surgeon to embark on a highly successful salvage operation. In the case of occult fistula, for instance, a small empyema may be removed by extrapleural decortication of the empyema and re-amputation of the bronchial stump[12] (Fig. 3). A postpneumonectomy empyema has been likewise removed

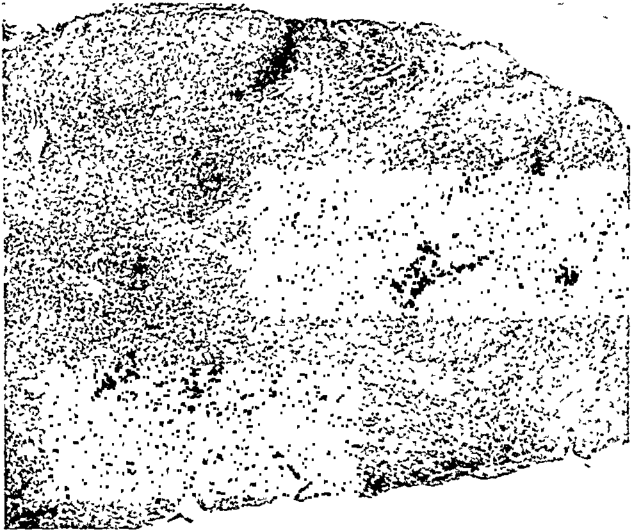

Fig 1.—Pure tuberculous empyema Photomicrograph of cross section of peel ×30 The tubercles are most numerous toward the inner surface of the envelope (above) The visceral juxtapleural edge (below) is free from tubercles

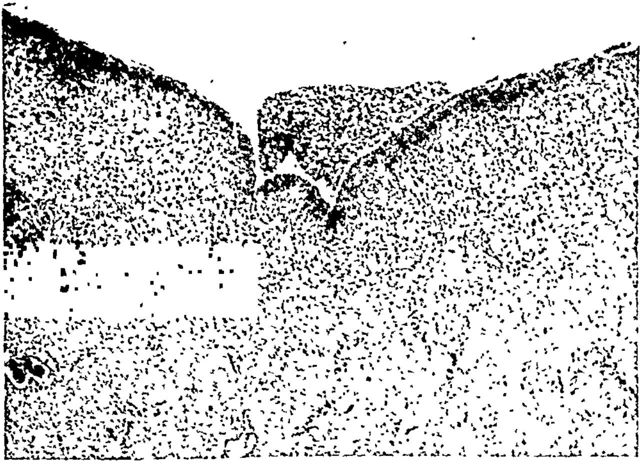

Fig. 2.—Pure tuberculous empyema. Photomicrograph of cross section of peel ×30. showing inner surface of empyema cavity. This patient had prolonged chemotherapy prior to operation. One sees only a nonspecific inflammatory reaction All evidence of specific tuberculous infection has now disappeared.

in toto. One patient in our series had three decortications because of air leaks and intrapleural infection following right upper lobectomy. The eventual result was satisfactory. Postresection intrapleural hemorrhage with organization is also a well-known indication.

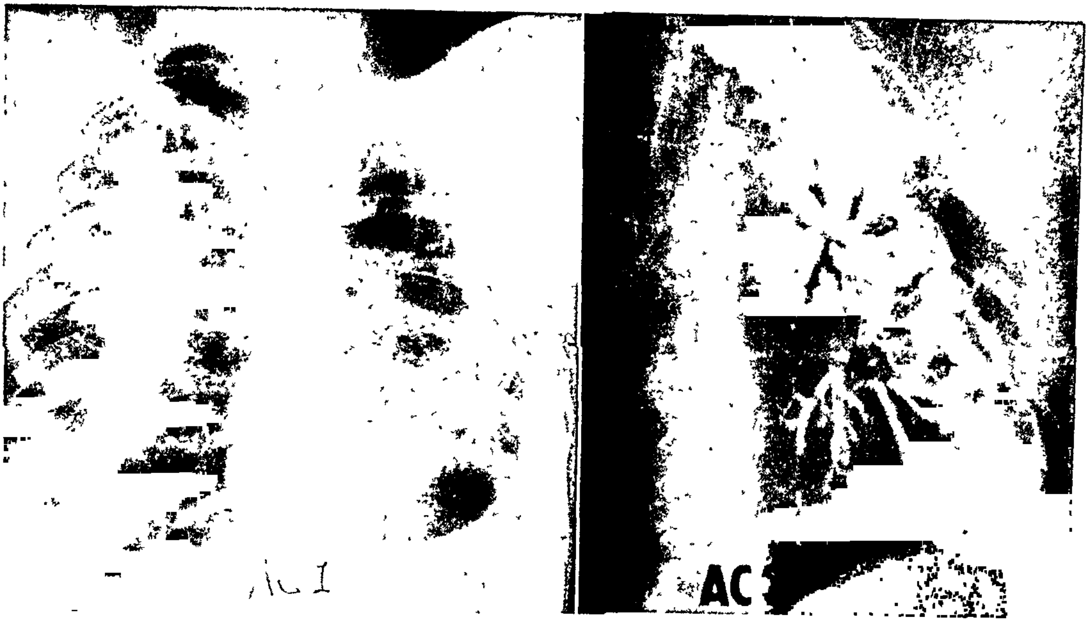

Fig. 3.—A patient with positive sputum which developed 4 years following left upper lobectomy and thoracoplasty performed elsewhere. The routine PA roentgenogram is unrevealing. The bronchogram demonstrates an occult fistula and empyema. Extrapleural exenteration of empyema with decortication and revision of the left upper lobe bronchial stump resulted in cure. (From Merrill, D. L., and Samson, P. C.: Am. Rev. Tuberc. 77: 561, 1958.)

PREOPERATIVE STUDIES

The final decision as to procedure depends upon the status of the underlying lung and this makes decortication in tuberculosis more complicated than when performed in other situations. It also means that frequently decortication may not be the sole operation, but is performed in conjunction with resection and/or thoracoplasty.

The status of the underlying lung must be studied in detail. Complete review of serial films, tomography, bronchoscopy, and bronchograms may all be indicated before a decision is reached. If the tuberculosis is inactive and originally not of great extent, it may be presumed that the lung can re-expand quite well. Decortication alone will then probably suffice. However, poor re-expansion may be expected in the presence of a high-grade stenosis of the mainstem bronchus and this may well be a contraindication to decortication. If there is active lobar disease or old pulmonary fibrosis, resection and/or thoracoplasty may be necessary in addition to decortication. Of course, a destroyed lung with pleural complications should be removed by the technique of pleuropneumonectomy.

Bronchograms are frequently valuable, but must be interpreted with care. In the absence of clinical symptoms, the widening and blunting of bronchi in

a collapsed lobe may not be anatomically permanent bronchiectasis but may be reversible on re-expansion following decortication (Fig 4)

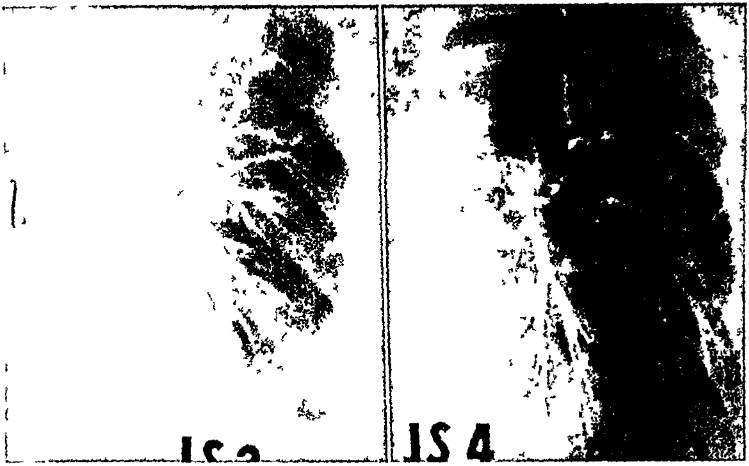

Fig 4 —Pure tuberculous empyema Pre and postdecortication bronchograms showing reversal of bronchiectasis in left lower lobe There were no clinical symptoms of bronchiectasis at any time (From Merrill D L and Samson P C Am Rev Tuberc 77 [illegible] 1958)

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The exact order of the concomitant operations most often applied in tuberculosis depends upon what is considered to be the main pathologic disorder In cases of empyema or unexpandable lung, decortication is the primary operation and the first procedure undertaken On the other hand, resection of some type may be proceeded with first and decortication of varying degree then

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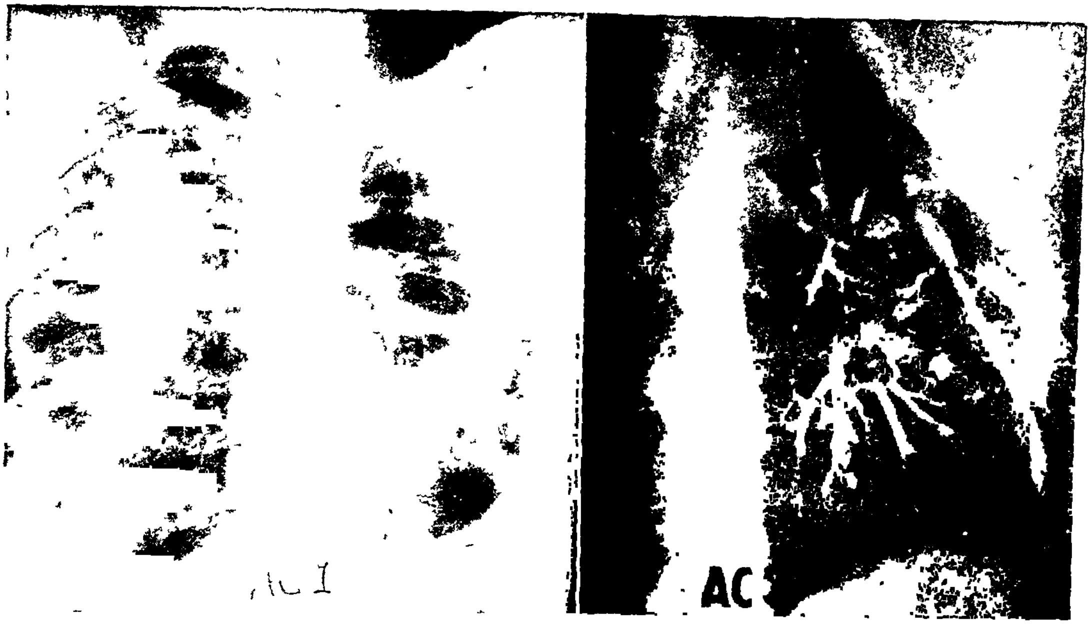

Fig 3—A patient with positive sputum which developed 4 years following left upper lobectomy and thoracoplasty performed elsewhere. The routine PA roentgenogram is unrevealing. The bronchogram demonstrates an occult fistula and empyema. Extrapleural exenteration of empyema with decortication and revision of the left upper lobe bronchial stump resulted in cure (From Merrill, D. L., and Samson P. C. Am. Rev. Tuberc. 77: 561, 1958.)

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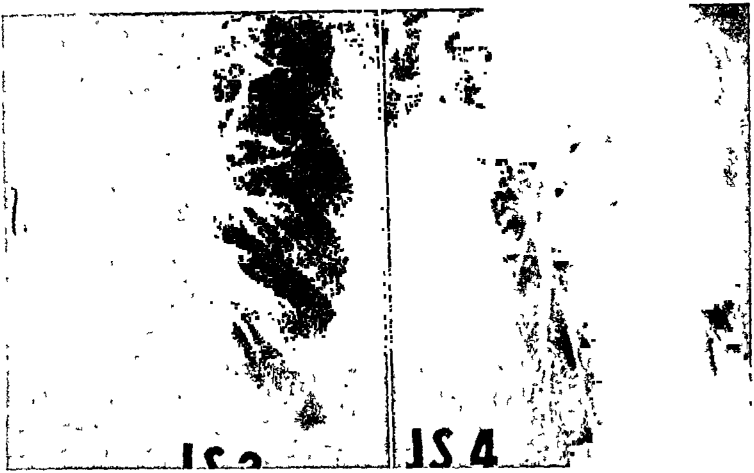

Fig 4.—Pure tuberculous empyema. Pre- and postdecortication bronchograms showing reversal of "bronchiectasis" in left lower lobe. There were no clinical symptoms of bronchiectasis at any time. (From Merrill, D. L. and Samson, P. C.: Am. Rev. Tuberc. 77: 361, 1958.)

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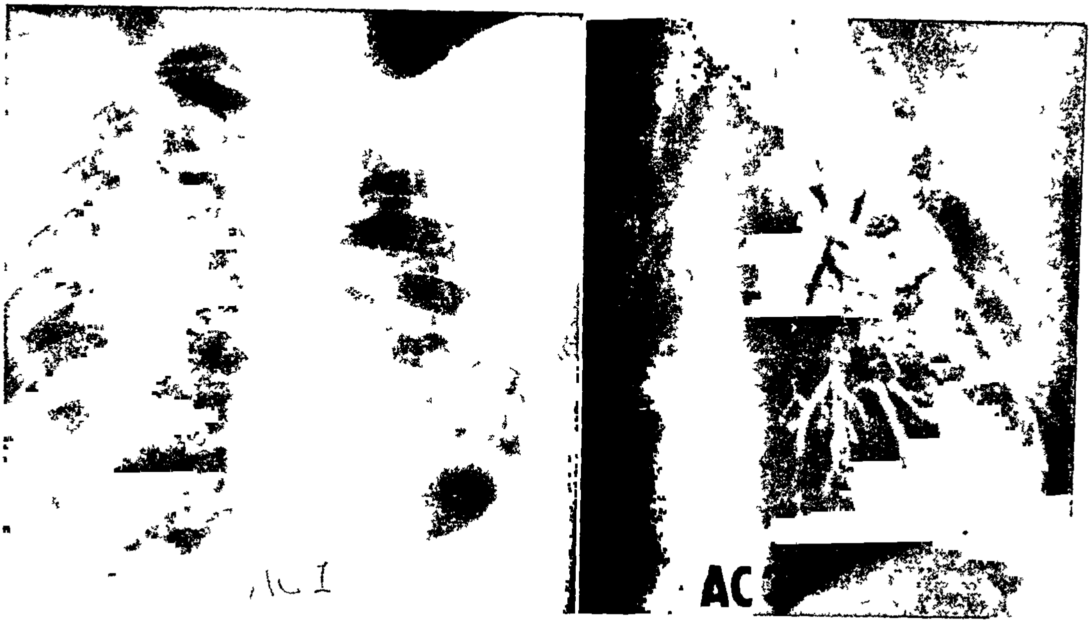

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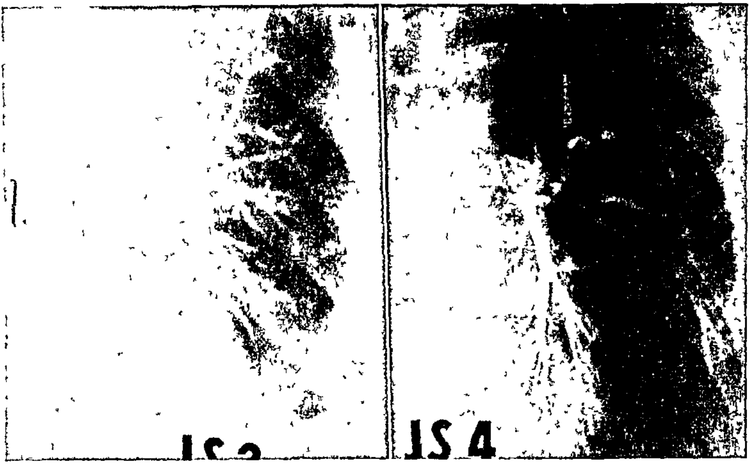

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Certain surgical principles have evolved in our clinics which apply to all types of decortication. Nonflammable anesthesia is used This allows the employment of the electrocoagulation which is a great timesaver in many instances in which multiple areas of punctate bleeding are present. The standard approach is posterolateral, removing the fifth or sixth rib We prefer to remove a rib because we believe that a more secure chest wall closu [illegible] formed. In general, fine nonabsorbable suture material is used th [illegible] lung tissue needs to be repaired, we employ fine catgut on an atraumatic needle. At least two right-angle drainage tubes of from 36 to 40 Fr. are used, one anteriorly in the second interspace and one posterolaterally in the eighth interspace. Occasionally a third and posterior tube is used, particularly when the superior segment of the lower lobe has been removed. If numerous small lung leaks persist, some type of suction must be employed and we have become accustomed to the use of high-vacuum, high-flow suction drainage with a negative pressure available, of from 25 to 50 cm. of water. Admittedly, there is continuing discussion that high, negative intrapleural pressures may help maintain fistulas. It is our present belief that this may well be true of *bronchial* fistula, but not of multiple small air leaks. High-vacuum suction seems the best means of obtaining prompt pulmonary re-expansion under the latter circumstances. Roe[13] has recently considered these matters at length.

General standards have been set up in caring for the chest wall in cases of prior drainage. Sinuses, including pleurocutaneous flap drainages of the Eloesser type, are excised down to the ribs, dissected loose, and turned in so they may be removed by the later intrathoracic operation. The chest wall is then closed in layers over these areas, instruments, gowns, and gloves changed, and the main thoracotomy incision made under sterile conditions. In the case of tube tracks which are expected to be in the proper place for drainage following operation, these may likewise be excised to remove scar tissue. However, we have not disturbed the more recent ones and have used the same drainage sites following decortication.

Recently, hypothermia has been used on several patients whose vital capacity was extremely low and when it was hoped decortication would improve ventilatory reserve (see Figs. 12-13). Within the past few months, Brewer and King[14] have independently reported on a similar use of this modality.

Proper antituberculosis drug coverage is of the greatest importance when the pleural and/or pulmonary disease is or has been infectious. If the organisms are sensitive, or if no tubercle bacilli are found, the standard drugs are continued through surgery and for many months thereafter. Streptomycin is placed in the pleural cavity only when there has been gross contamination, but we must confess that we have no statistical justification for its use intrapleurally. When the tubercle bacilli are resistant to streptomycin, PAS or INH, we consider it mandatory to use other drugs. Pyrazinamide, viomycin, or cycloserine are generally preferred. The drug of choice is commenced some 14 days before operation and continued from 4 to 6 weeks postoperatively. In mixed infection empyema, sensitivity studies are performed on the pyogenic organisms present and the appropriate antibiotic is then added to the regimen and continued for from 7 to 10 days following surgery.

THE UNEXPANDABLE LUNG-PNEUMOTHORAX COMPLICATIONS

The nonexpanded lung due to pneumothorax, or primary pleural effusion, represents a double hazard to the patient: there is loss of pulmonary function which is at least partly restored by decortication; persistence of a space invites infection sooner or later.

Decortication under these circumstances is a simple, effective, and highly safe procedure with excellent results. Using the standard approach, the parietal peel is incised and the center of the envelope entered directly. Standard visceral pleural decortication is carried out under intermittent positive pressure by the anesthetist. Depending upon the size of the pocket, its duration, and a previous knowledge of whether the chest wall is fixed, we may or may not do a parietal pleural decortication. It is not routine as it increases the operating time and the bleeding. If the pocket is a lateral one, it is well to separate all areas of adherence between visceral and parietal pleura down to the diaphragm and to the hilum so that circumferential expansion can take place. In most cases of this type, there has been no need for either resection or thoracoplasty (Fig. 5). Rarely, the discovery of a fibrotic, poorly expansile lobe has led us to perform a tailoring concomitant thoracoplasty.

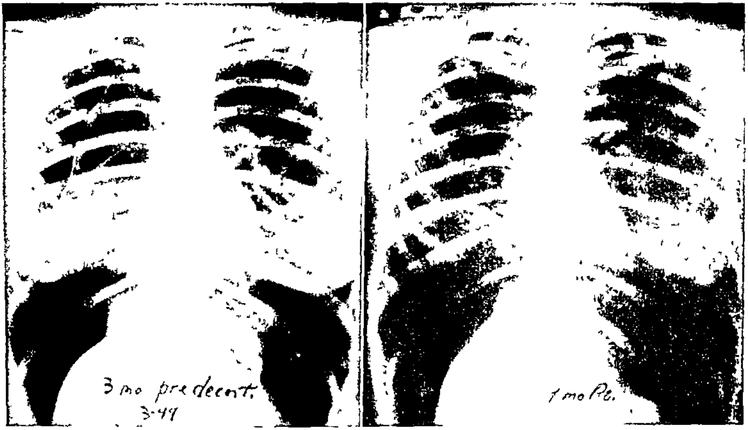

Fig. 5.—Excellent result from decortication for unexpandable lung following pneumothorax therapy of 5 years' duration.

Granted that few pneumothoraces are induced these days, we should nevertheless include a word on the management of the complicated ineffectual pneumothorax. In spite of the most careful management and early abandonment of an ineffective pneumothorax, there may be prompt fluid formation. By implication, the pulmonary disease is almost always active. If the lung cannot be immediately re-expanded by aspiration, early surgery is indicated. In general, thoracotomy with evacuation of fluid, decortication of the normal lung, and possibly lobectomy should give a more satisfactory result, although surgical drainage of an *infected* pleural cavity may be the preferable alternative.

If lobectomy is indicated as part of the procedure but, bronchoscopically, the bronchus is not considered suitable for transection, a tem [illegible] rapleural thoracoplasty may be instituted to help control [illegible] as well as obliterate the pleural cavity. Occasionally [illegible] pneumothorax is ineffective in closing a lobar cavity. Re-expansion is not successful because a fibrous membrane has developed. In this situation, we favor decortication, lobectomy, and possibly concomitant thoracoplasty, or postoperative pneumoperitoneum. Here, decortication is essential for adequate re-expansion of the remaining lobe (Fig. 6).

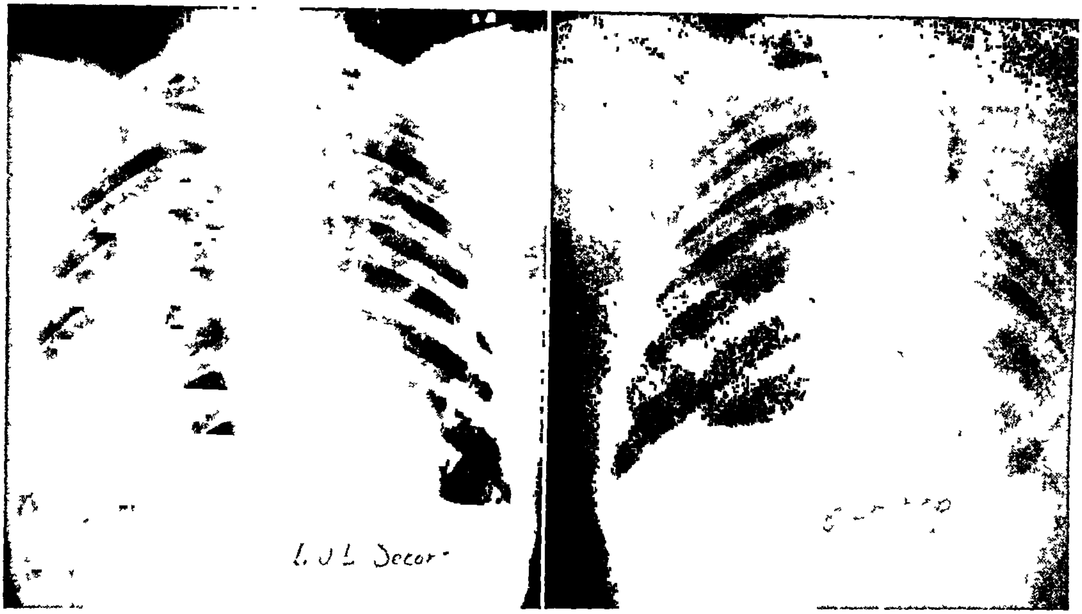

Fig. 6.—A technically adequate pneumothorax, but there is a residual cavity in the left upper lobe and beginning fluid formation. Postoperative roentgenogram following decortication, left upper lobectomy, and concomitant thoracoplasty (ribs 2, 3, 4).

THE "FALSE RE-EXPANSION"

This condition usually has been a complication of pneumothorax or primary pleural effusion. Obliteration of the pleural space by mediastinal and cardiac shift rather than by effective pulmonary re-expansion has resulted in continued disability because of tension phenomena affecting the heart, thoracic parietes, or diaphragm. A calcium plaque may rarely develop. The patients in this group have been few but a greater number may well be symptomatic. We suggest that a critical review of patients whose pneumothorax has been abandoned might turn up an appreciable number of candidates for operation. These patients present a varying symptomatology. Frequently the symptoms are not crippling but very annoying. Persisting thoracic discomfort or actual pain, made worse by exertion; dyspnea and breathlessness, pressure sensations in the chest; chronic fatigue; recurrent formation of fluid; palpitation and tachycardia; and "asthma" have all been recorded. In 1 patient, a systolic heart murmur became progressively louder apparently due to cardiac torsion (Figs. 7 and 8). On examination, these patients have flattened chests on the affected side. The intercostal spaces are narrowed and retracted, and limited inspiratory expansion is quite obvious (Fig. 9). In the few patients, decortication, where employed, has been highly successful; Mulvihill[3] and others have likewise operated in similar situations to improve pulmonary function and thus allow for needed surgery on contralateral active lesions.

At operation, the peel will be double layered and, in general, the two layers will be adherent They may, however, be intermittently separated by small lacunae of fluid or by coalescent calcium deposits (Fig 10) The latter are always on the inside of the envelope and parietal pleurectomy may well be advisable when dealing with calcium so that the whole plaque may be removed in

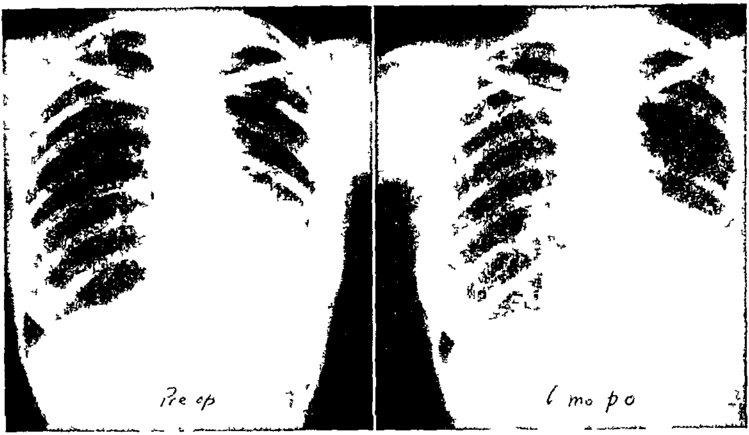

Fig 7 — False re expansion following 5 years of pneumothorax therapy Complaints of tightness in chest and fatigue Progression of systolic cardiac murmur from Grade I to Grade IV with re expansion Following decortication loss of symptoms and marked regression of murmur

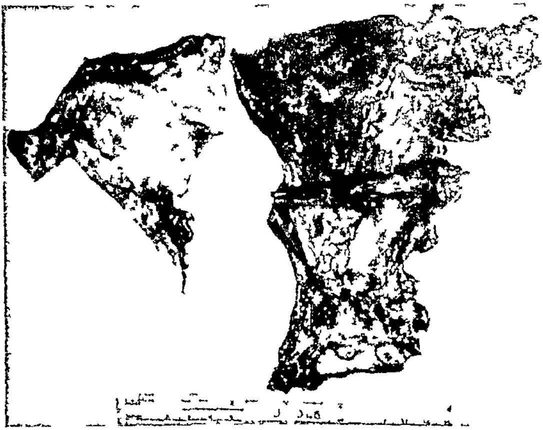

Fig 8 —Peel from patient shown in Fig 7 There is demonstrated the reflection from visceral to parietal and diaphragmatic surfaces The fibrous tissue composing the peel was rigid and relatively avascular

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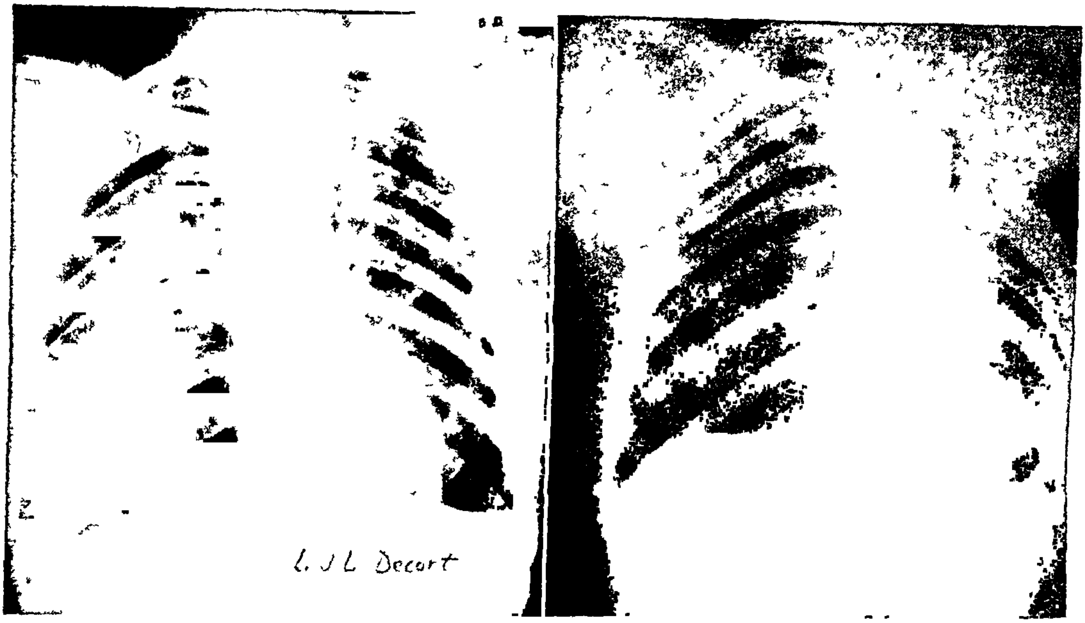

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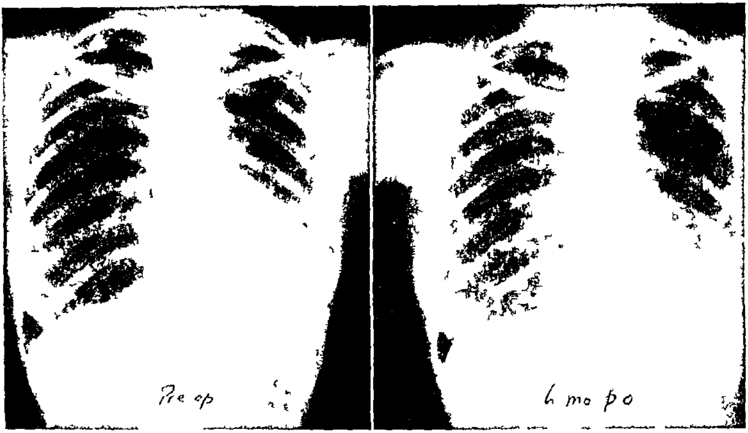

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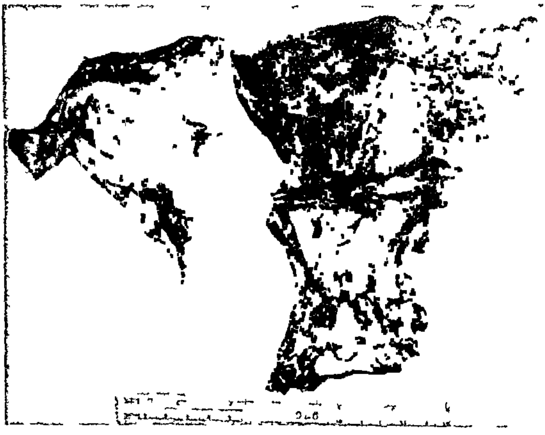

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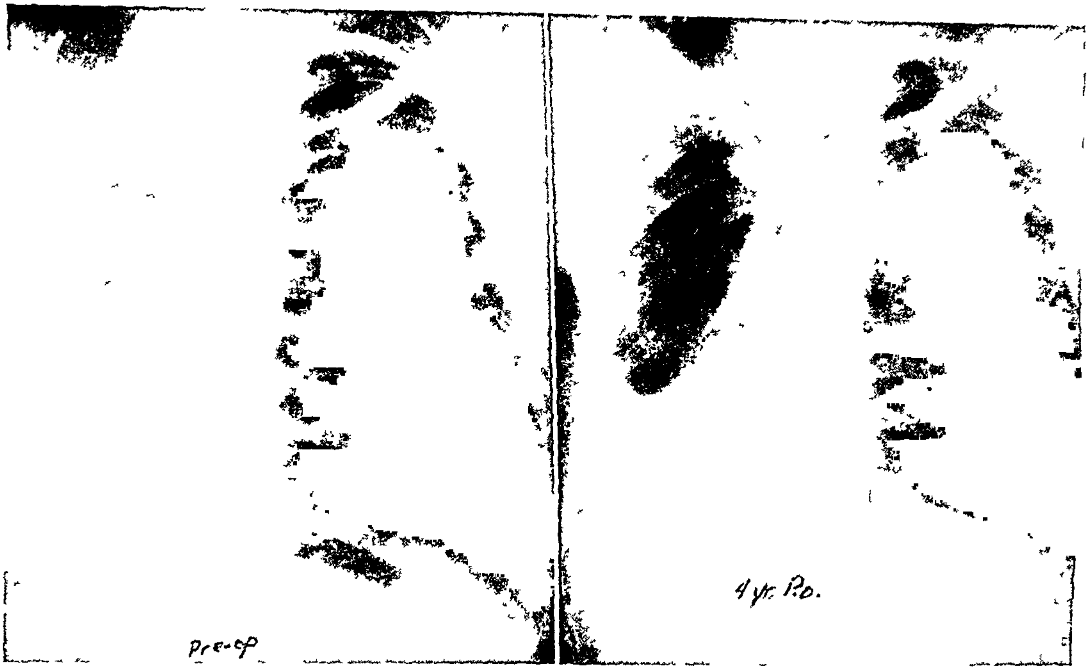

Fig 9—Inactive tuberculosis False re-expansion following 16 years of pneumothorax therapy. Decortication A poor radiologic result Clinically, patient has lost all preoperative symptoms of dyspnea, thoracic pressure, tachycardia, and frequent colds

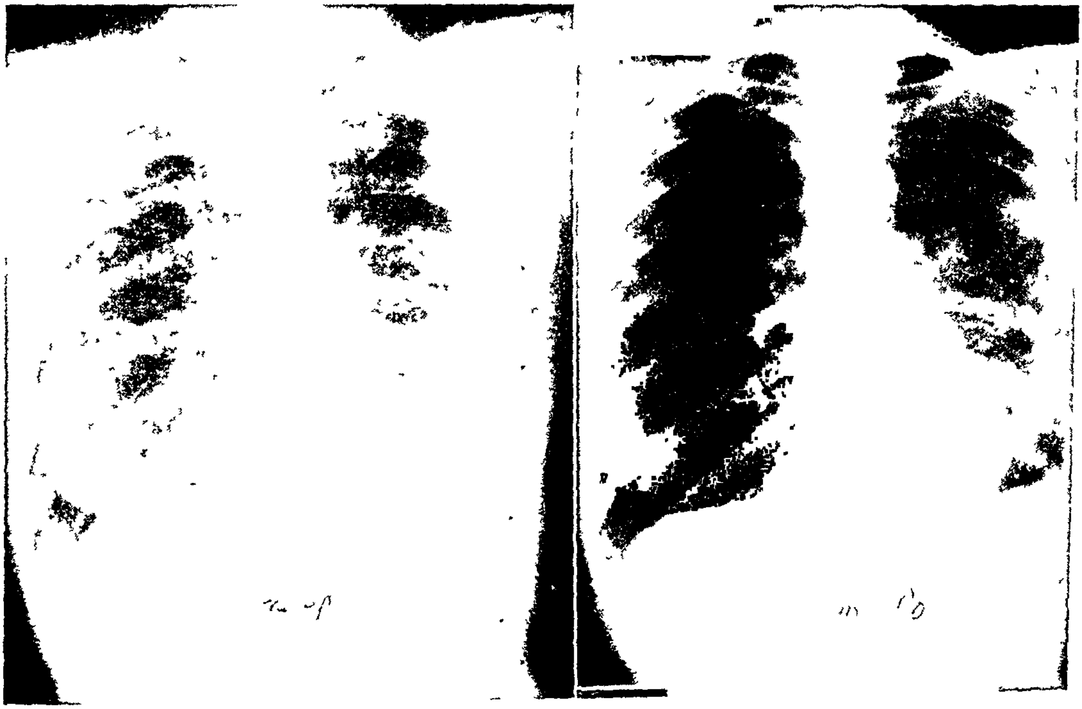

Fig. 10—A woman, aged 48, with presenting complaints of thora
severe cough, intermittent "asthma," and intermittent fever Artifici
cated by fluid 30 years before "False re-expansion." Extrapleural
cation of sac containing large calcium plaque The scanty fluid in the envelope contained viable tubercle bacilli Today she is without symptoms.

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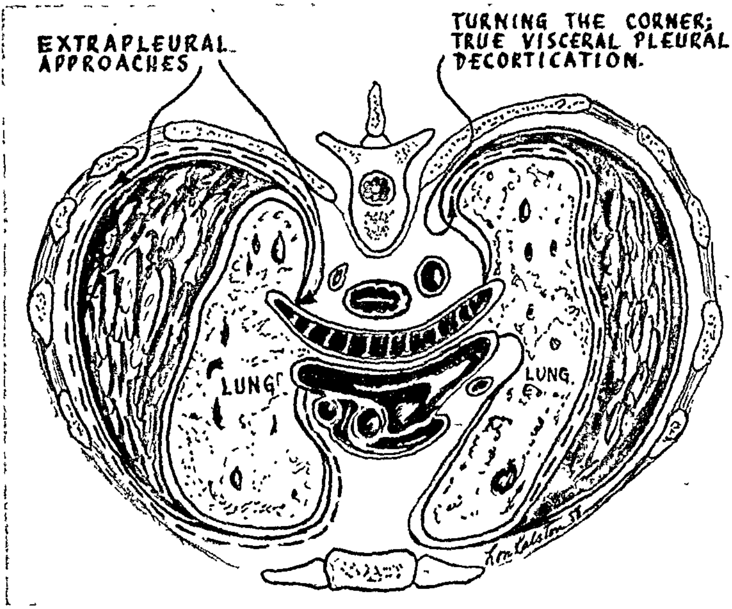


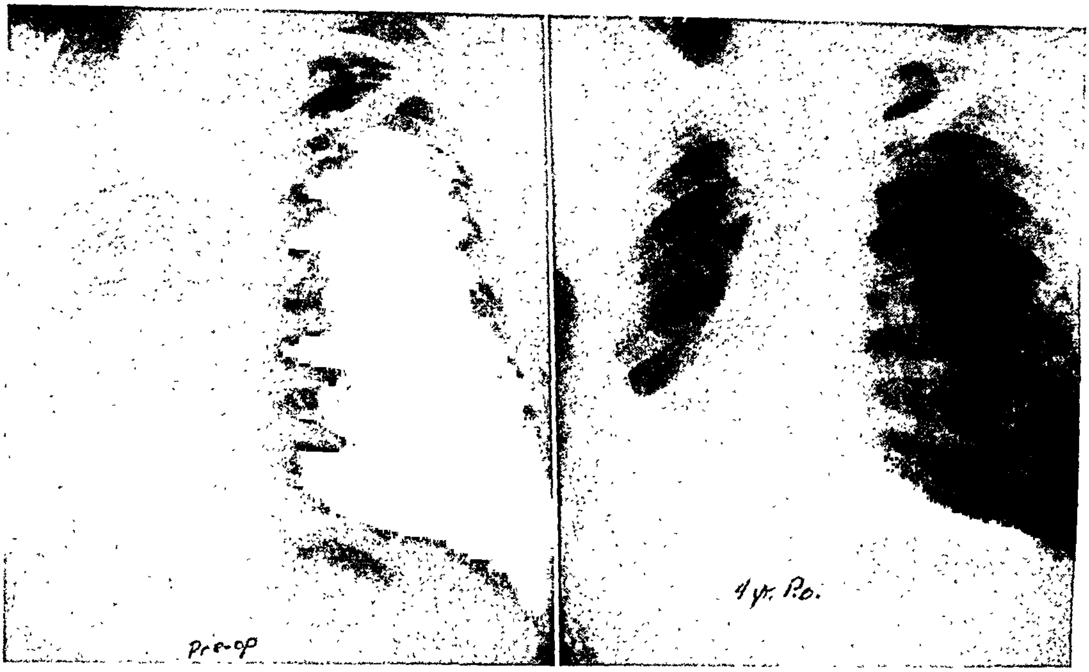
Fig 11.—Diagrammatic sketch of surgical approaches On the left is demonstrated the principle of extraparietal pleural dissection for the preliminary freeing of an empyema sac, or the dire[illegible] On the right is demonstrated a change [illegible] of the parietal pleura "at the corner." [illegible] [illegible]ken and the envelope removed en masse

EMPYEMA

Decortication has made the greatest difference in the treatment of empyema.

In acute pyogenic empyema, it has generally been considered proper to perform a preliminary surgical drainage. The empyema might well become obliterated, but this has been rare in our experience when the pyogenic infection was a complication of an established pneumothorax. Decortication would then be necessary after the empyema had become stabilized (Figs. 12 and 13). In selected instances, we believe that primary thoracotomy and decortication without preliminary drainage is a logical procedure.

In chronic empyema from whatever source, one has but to remember the deforming extrapleural and Schede thoracoplasties of yesteryear to realize how much better off are these patients today. The surgical management of chronic



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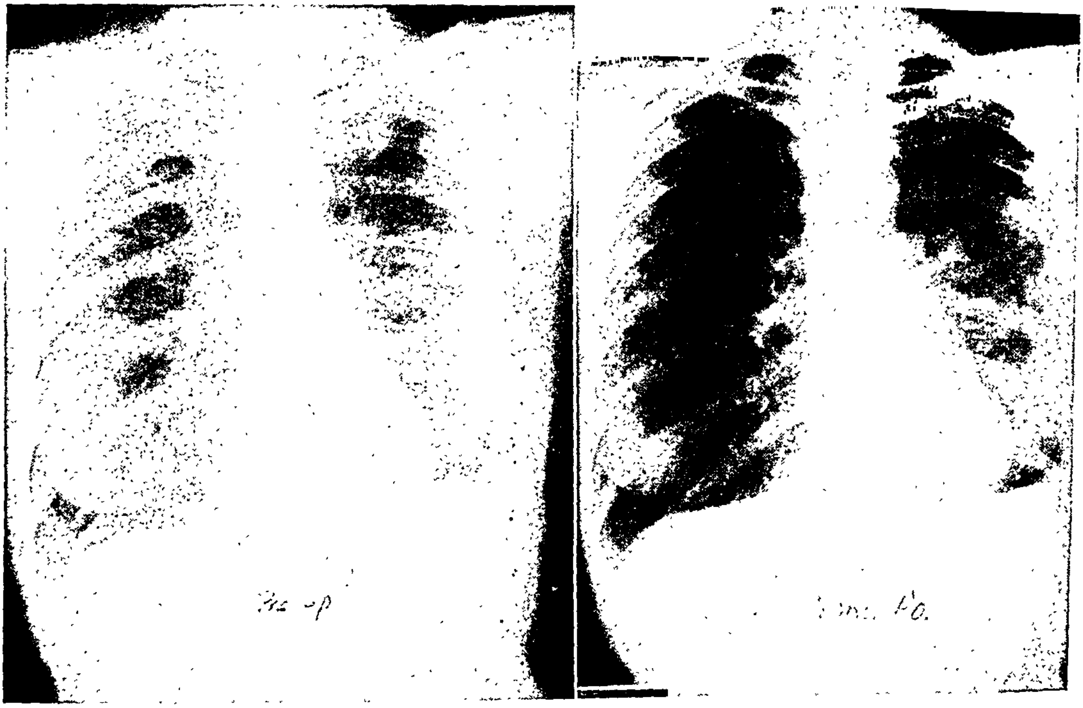

Fig. 10.—A woman, aged 48, with presenting complaints of thoracic discomfort, weakness, severe cough, intermittent "asthma," and intermittent fever. Artificial pneumothorax complicated by fluid 30 years before. "False re-expansion." Extrapleural exenteration and decortication of sac containing large calcium plaque. The scanty fluid in the envelope contained viable tubercle bacilli. Today she is without symptoms.

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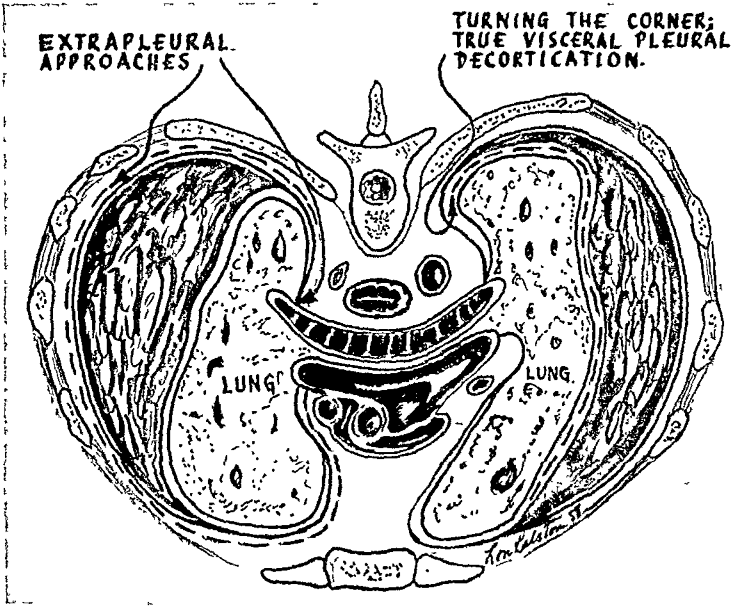

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In chronic empyema from whatever source, one has but to remember the deforming extrapleural and Schede thoracoplastics of yesteryear to realize how much better off are these patients today. The surgical management of chronic empyema in tuberculosis embodies the principle of attempting *to remove the entire empyema sac or envelope without opening or spilling the contents.* It is surprising how often this can be accomplished even with an empyema of 20 years' duration. This basic technique as stressed by Weinberg[4] and others was first independently employed by us in mid-1947 (Fig. 11).

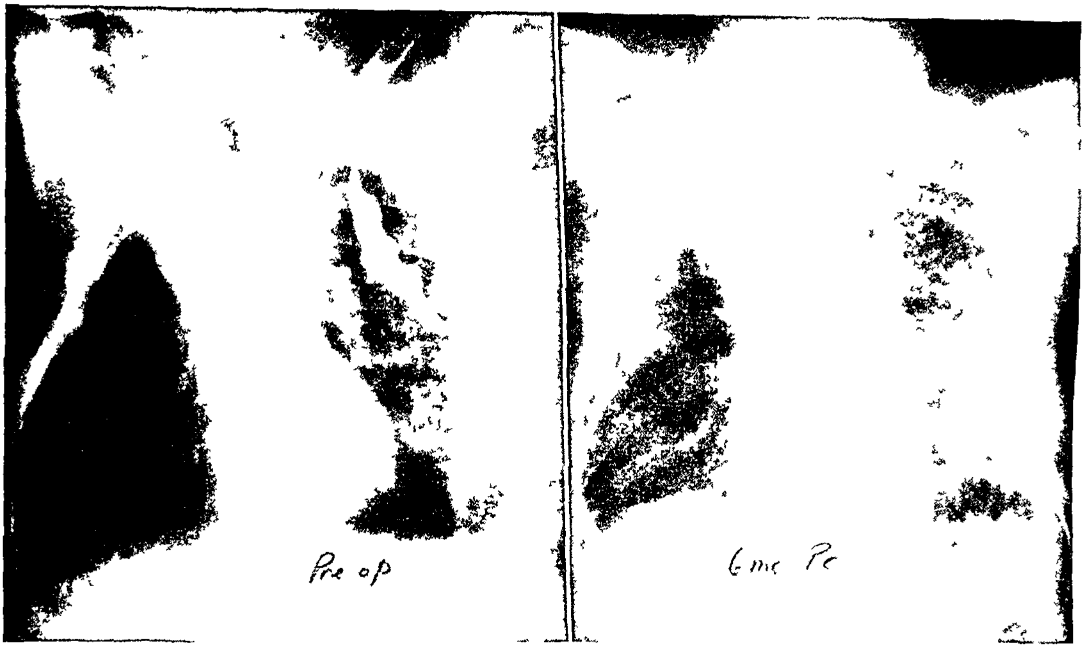


Fig 12 —A 43-year-old man with inactive tuberculosis Right bilobectomy and concomitant thoracoplasty 4 years before Left pneumothorax complicated by pyogenic infection previously drained *Patient dyspneic on slightest exertion* Resting pulse frequently over 100 Left chest fixed Under *hypothermia*, extrapleural exenteration of empyema and decortication During the 5-hour operation, the pulse averaged 70 At present, the patient's left thorax *is movable and without draining sinuses He is not dyspneic on moderate exertion*

Fig 13 —Cross section of peel from patient demonstrated in Fig 12 The parietal segment (below) was mobilized extrapleurally The "corner" (to the right) was turned by incising the parietal pleura and developing a line of cleavage between visceral pleura and peel (above).

On the chest wall side, the parietal pleura is removed with the peel most of the time, a fact not generally appreciated Actually, we do parietal pleurectomy from preference because a cleavage plane is far more easily developed extrapleurally than it is between pleura and peel; likewise there is much less chance of breaking into the envelope. With the outer portion of the empyema sac completely freed from the chest wall, there is sometimes difficulty because of

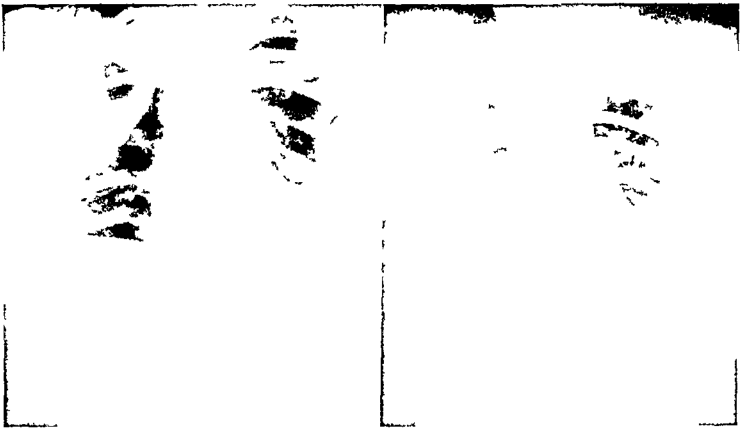


Fig 14—Chronic tuberculous empyema of 4 years duration This was the earliest of our en bloc exenterations of an empyema sac Performed April 4 1947 There was no chemotherapy employed

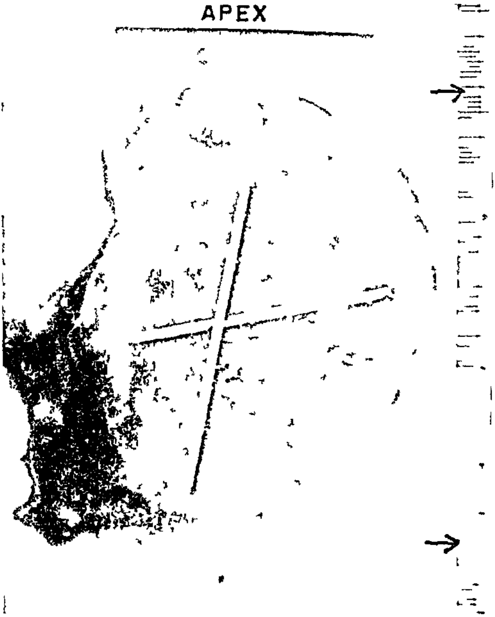


Fig 15—Opened mediastinal aspect of empyem c fro ent shown in Fig 14 showing the rough and granular appearance of th sur he envelope Microscopically this peel showed extensive tuberculous

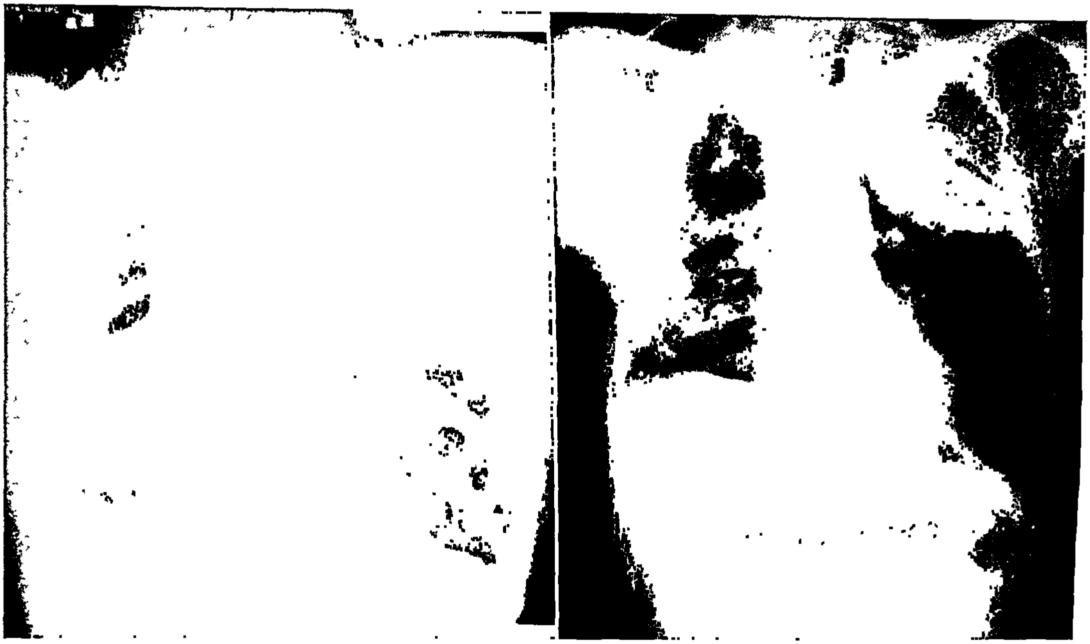


Fig. 16.—Far-advanced inactive tuberculosis with fibrotic right upper lobe. Left extrapleural oleothorax. Right mixed infection empyema: ~~pneumothorax, 15~~ years; tuberculous empyema, 13 years; pyogenic invasion, 3 months, controlled by aspiration and antibiotic injection. Total en bloc removal of empyema sac without spillage, and concomitant thoracoplasty, ribs 2-6. Patient now employed full time as a schoolteacher.

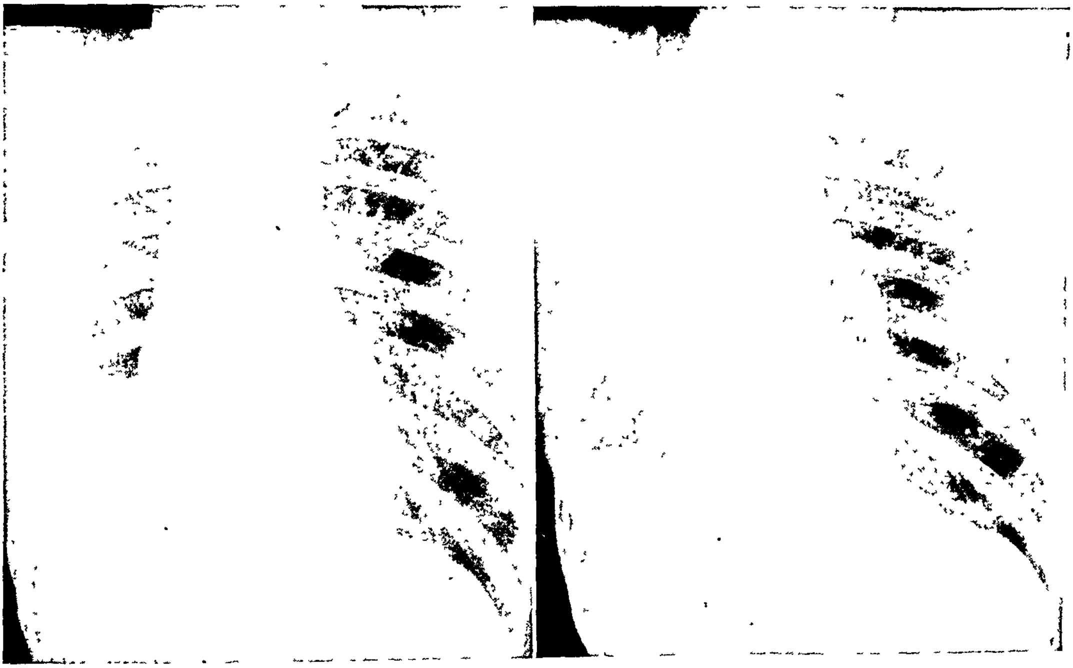
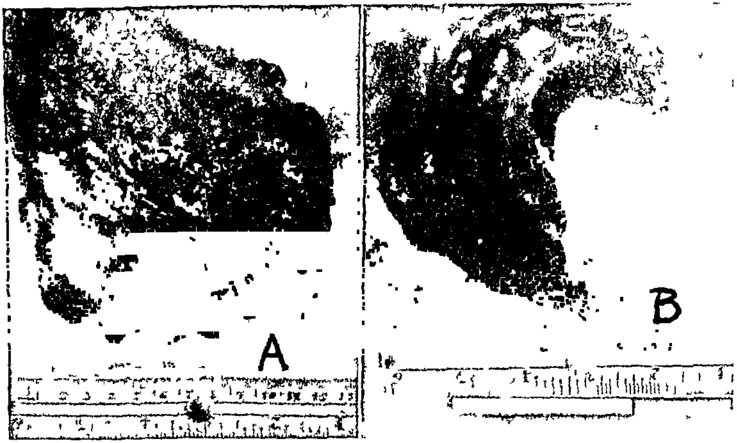


Fig. 17.—Pure tuberculous empyema of 5 years' duration. Fibrosis of right upper lobe. Extrapleural removal of empyema sac with visceral decortication was followed by poor expansion. A secondary thoracoplasty was successful in obliterating the apical pocket.



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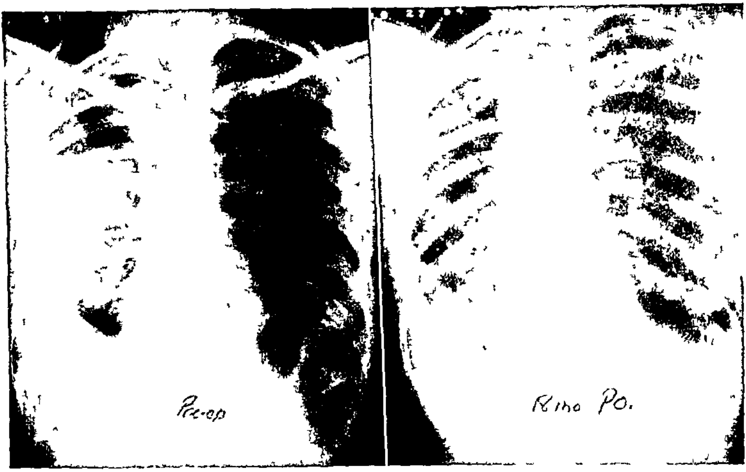

Fig 19—A 39 year-old woman with inac … rax of nearly 12
years duration and … Vital capacity,
1 500 c c Maximum … mobilization of
empyema sac and rer … (operation by Dr
K. L Hardy) An … nt in ventilation
studies

fullness of the sac. A bit of technique sometimes forgotten is to plunge a large-bore needle with suction attached into the empyema cavity and remove fluid and/or air to the greatest extent possible. This will collapse the sac and thereafter there will be plenty of room to work The critical point of the operation employing pleurectomy is recognition of the exact line where the two pleurae

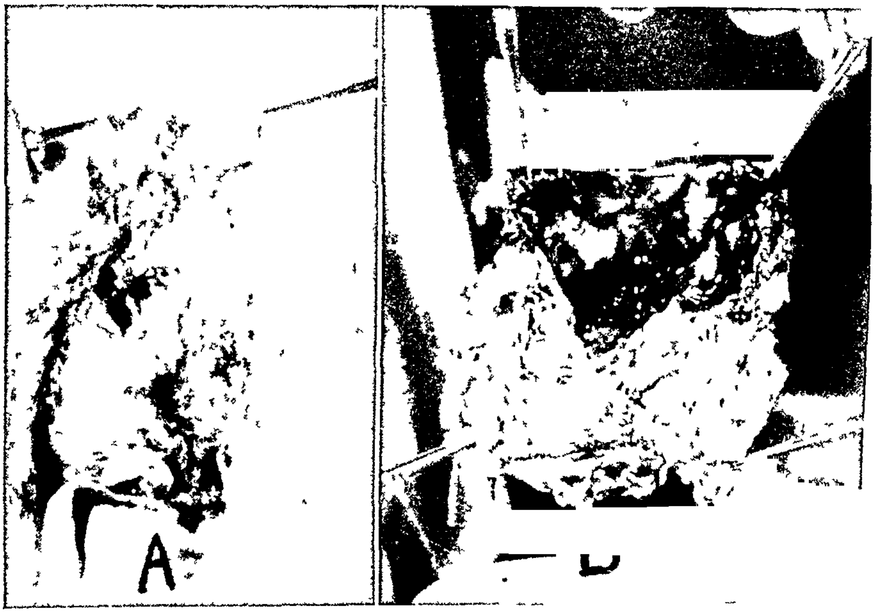

Fig 20.—The surgical specimen from patient shown in Fig 19. *A*, Mediastinal (visceral pleural) aspect of empyema sac *B*, Interior of sac showing shaggy fibrin and amorphous debris

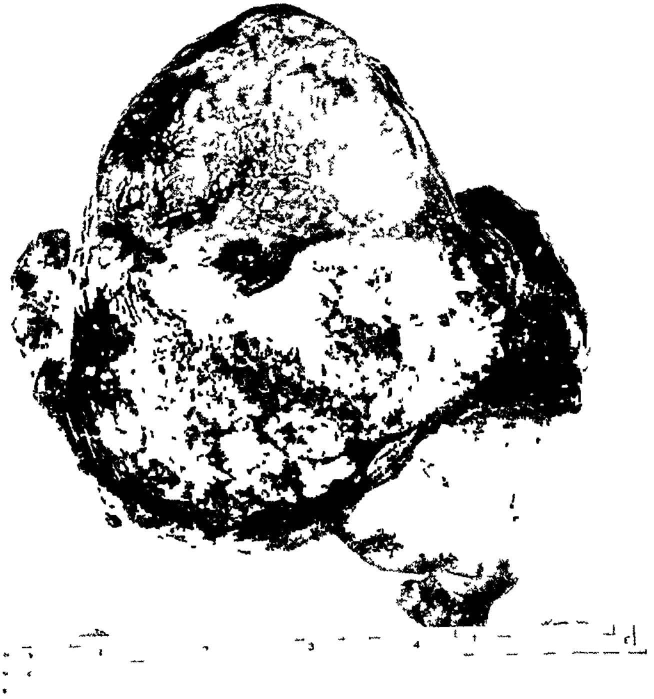

Fig 21.—Destroyed lung and empyema sac removed together en masse by extrapleural approach and pleuropneumonectomy

themselves come into apposition. When this point is reached, further extrapleural dissection is unnecessary and unwise. The cleavage plane should then be changed from extrapleura [illegible] entified and freed. One can then cor [illegible] by degrees, complete a true decortication When the technique is successful, a bag

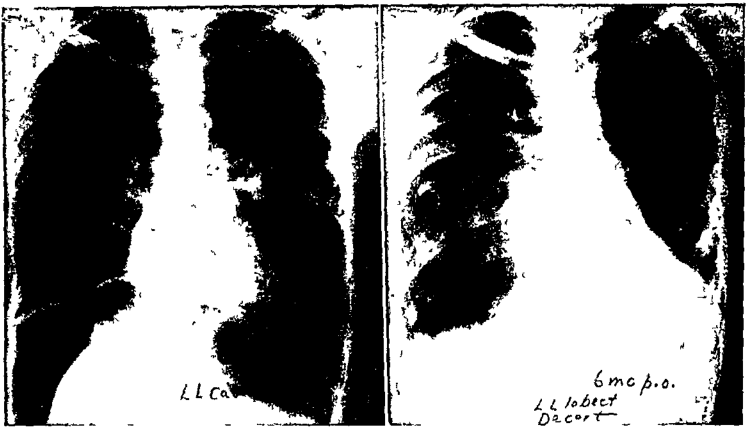

Fig 22—Pre- and postoperative roentgenograms of a patient who had left lower lobectomy and incidental decortication of the left upper lobe The preoperative film gives no hin as to the extent of the peel

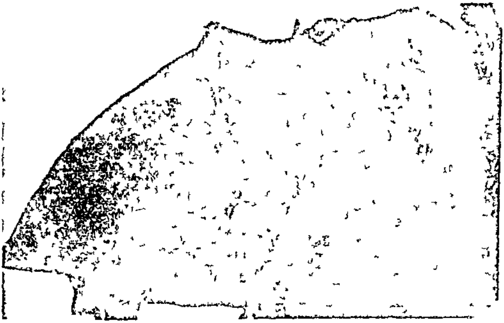

Fig 23.—The peel from patient shown in Fig 22. It is 2 mm in thickness, firm and inelastic Satisfactory re-expansion of the left upper lobe would have been impossible without adequate decortication

filled with pus may be totally removed from the thoracic cavity without leakage of contents The advantages, particularly, in tuberculous infections, are obvious (Figs 12-20). A natural extension of this means of treating empyema is the technique of Sarot[15] in which the extrapleural separation is carried to the hilum and pneumonectomy performed Thus, a destroyed lung and an en [illegible] can be completely exenterated en masse without spilling (Fig. 21

recorded in 104 cases (78 per cent). The complications in 26 cases (19.7 per cent) were considered primarily the result of the resection rather than of the decortication.

Unfortunately, we cannot present a large number of pre- and postoperative pulmonary function studies. In the past,[16] a fear has been expressed that some poorly expansible lungs might actually be a detriment to the patient, postdecortication, because of decreased ability to oxygenate blood. We have seen no patient in which this became clinically evident. It is our belief that living aerating lung, even though poor functionally, is a better "filler" for the hemithorax than are inert plastics or organizing blood and serum.

SUMMARY

1. A study has been made of 237 patients undergoing decortication during the past 10 years. *In 104 of these, decortication was the main operation;* in 133, it was incidental but an important adjunct to the more major resection. The over-all mortality was low (2.9 per cent) and the results generally satisfactorily.

2. Relief of thoracic discomfort and dyspnea, removal of sources of actual or potential infection, and adequate hemithoracic restitution were recorded in 77 per cent.

3. Decortication has been indicated in the following general classifications: the unexpandable lung due to long-term pneumothorax therapy, or primary pleural effusion; the "false re-expansion"; pyogenic, pure tuberculous, and mixed infection empyema; decortication incident to resection.

4. The technical details of decortication in the various categories have been described.

5. It has been stressed that frequently decortication may necessarily be combined with pulmonary resection and/or thoracoplasty depending upon the status of the underlying lung (bronchial stenosis, fibrosis, active tuberculous infection, clinically evident bronchiectasis).

6. Properly employed, decortication with or without parietal pleurectomy has proved itself a safe and effective procedure in treating the pleural complications of pulmonary tuberculosis.

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DISCUSSION

DR JOSEPH GORDON, Albuquerque, N M—I should like to carry on the discussion which you have just heard regarding the thin membranous peel reported in some types of cases In decortication done for re expansion, if the cortical peel is not carried down to the visceral pleural surface this thin membranous material, that looks almost exactly like visceral pleura, may be left behind and the re expansion is not nearly so good When this membranous peel is removed, unfolding of the lung occurs, yielding maximum inflation I should like to show some slides of this thin membranous material

Dr Samson showed in his second slide the thick visceral cortical peel removed, and evident in only one area was a portion of the small, thin membranous material

(slide) In this particular slide, we show the dense cortical peel and the thin membrane which you can readily see

(slide) In this next slide is shown the thin membrane that is removed separately showing a moderate amount of elastica

(slide) On further examination of this peel, in the next slide, we see these pleural clefts, large ovoid space in which there is a group of cells which are mesenchymal in origin This is the thing which in my opinion is responsible for the development of an unexpandable lung The details of the method by which the lung remains unexpanded have not been thoroughly explained The primary development of this membrane over the collapsed lung is apparently the cause

(slide) One can see another of the clear spaces with the small blood vessels contained therein These mesenchymal cells therefore are not arising from the blood vessel itself but are a separate entity

There apparently is some trigger mechanism which is not yet clear and which, when the lung is under collapse, apparently causes this membranous material to develop This thin membrane, not unlike the visceral pleura, holds the lung down so that it cannot re expand From this point onward it is easy to explain why we have the development of a dense cortical peel The fibrin organizes into fibrous tissue and the lung is obliged to remain down But, in order for this to occur, it is necessary for something to prevent the lung from fully re expanding as it normally would The membranous development may happen whether it is a hemothorax, whether it is a pyogenic empyema, whether it is long standing pneumothorax with the presence or absence of fluid I bring this to attention so that it might be given further study in other areas

DR ELMER P R MAURER, Cincinnati, Ohio—I would like to emphasize the superiority of complete extirpation technique over that of simple decortication My associate, Dr. Mendez, and myself during the past 5 years have preferred complete excision of the pleural pocket, regardless of the etiological background. I would like to show a few slides to illustrate the method.

(slide) This individual had a massive fibrohydrothorax of several years' duration.

(slide) This shows the complete pocket. We make the same effort as described by Dr. Samson to free the pocket in the extrapleural plane from the thoracic parietes all the way around to the midpleural reflection. We also free it from the diaphragm and then deliver the pocket with the attached lung out through the chest incision. If the lung is then placed on positive pressure it can be used as a "dissecting board" for conventional decortication.

This slide shows the pulmonary aspect of the hydrothorax pocket; (slide) the chest wall aspect; (slide) postoperative film 10 days after operation.

(slide) This is a massive infected oleothorax, instituted therapeutically in 1940 and removed by us in 1953. The tremendous size of the pocket is obvious.

(slide) A tuberculous empyema which was completely removed.

(slide) Chest wall surface of a large pocket, the etiology of which we did not know until it was completely removed.

(slide) After examination of the specimen in the laboratory, we were extremely pleased that we had used the circumferential excision technique because this lesion was due to blastomycosis.

We certainly feel that the technique for complete removal of the pleural pocket is surgically sound and attended with minimal blood loss. It obviates contamination that would be unavoidable by the conventional decortication procedure and permits more rapid and complete return of normal chest wall and lung function. Contamination in the last case presented would have been disastrous.

DR. DAVID H. WATERMAN, Knoxville, Tenn.—As the result of the work of Paul Samson and the others who re-introduced decortication during World War II, this procedure needs no defense before our Association.

I am particularly gratified that Dr. Samson has had an experience comparable to ours in false re-expansion. No residual pleural space need be present in order to do a successful decortication, as he pointed out. When we presented our work on decortication before this Association 2 years ago, we showed that progressive return of pulmonary function in such cases would continue to take place over an 18-month period.

As to empyema, I would like to again pay tribute to the late Dr. Carl Eggers, former President of this Association, for his brilliant pioneer work in decortication after World War I. He successfully performed the same operation we are doing today in both tuberculous and nontuberculous empyema without, of course, the benefit of antibiotic protection.

There was considerable interest manifested in the cases of decortication for malignancy which we included in our series 2 years ago. Of the 5 cases presented, the first was done in 1945. Since the report we have performed several cases, one of which I should like to present at this time.

(slide) The patient was a 49-year-old woman who had a 3-month history of progressive dyspnea and chest pain, and who presented herself with this pleural effusion on the right side which required repeated aspiration. Cytologic examination of the pleural fluid for malignant cells was negative. When the chest was opened to obtain a pleural biopsy, the nature of the peel was felt to warrant a decortication. Grossly, the thickened pleura was indistinguishable from that found in cases of persistent tuberculous effusion. Microscopically, it was found to be metastatic carcinoma.

(slide) This is the x-ray of the chest some 5 months after decortication. The pleural space is completely obliterated, the right lung appearing quite normal. The patient is entirely free of symptoms, has gained weight, and is working regularly. The primary site of the carcinoma is still not apparent.

(slide) This is the thick peel removed at decortication. I think you will agree that, with such a peel, the effusion would not respond to conservative therapy such as intrapleural nitrogen mustard.

ACHALASIA OF THE ESOPHAGUS: FURTHER THOUGHTS ON SURGICAL MANAGEMENT

Wm. M. Tuttle, M.D., Robert T. Crowley, M.D. (by invitation), and Raymond J. Barrett, M. D. (by invitation,) Detroit, Mich.

ACHALASIA of the esophagus is not a new disease. Purden[1] (1821) is usually thought of as the first to describe it. Hurst,[2] in 1934, stated that Willis had reported a patient, who was obviously one with achalasia, over a century and a half before Purden's report.

As was common to all disorders of that type located in portions of the body beyond the reach of surgery at that time, nothing was done. Both of the reports were made on the basis of autopsy material.

It required time to come to conclusions on an operative approach. This, apparently, came at the turn of the nineteenth and twentieth centuries.

Throughout the first decade of the twentieth century, various and sundry procedures were done, such as plication of the esophagus in an attempt to narrow the size of the lumen and, also, the removal of strips of the esophagus in the hope of the same result.[3, 4] These were not altogether successful. In 1910, Wendel[5] performed an operation in which an incision was carried through the entire layer of the lower esophagus and upper stomach at the gastrocardiac junction in a vertical line and then sutured the mucosa and the muscularis in layers horizontally. Such an operative procedure had been suggested by Marwendel[6] some years previously.

Heller[7] (1913) suggested and performed an anterior and posterior myotomy of the esophagogastric junction. The incision was carried only to the mucosa. He felt that the double incision was needed, in the fear that scarring postoperatively along the incision might well lead to a return of symptoms from further narrowing.

Heyrovsky[8] (1912) performed an esophagogastrostomy, in which the fundus of the stomach was anastomosed to the esophagus in the side-to-side line. The idea was the result of previous experimental work done on animals.

In 1915, Girard[9] performed, on 2 patients, a modification of the Wendel type of procedure, in which only the muscularis of the upper portion of the cardiogastric junction and the lower portion of the esophagus was incised

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Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

down to the mucosa and then the layers were sutured in a transverse direction. This, apparently, was successful in both instances. Ferdet and Weber[10] had suggested a similar procedure some 5 years before. Apparently Girard did not report his operative approach or his results, and, consequently, the approach lay buried for a number of years.

Throughout the remaining two decades, direct approach to the disease covered in this discussion was, with the exception of sporadic attempts, given up, and the treatment for achalasia became almost routinely one of bougienage and other methods of dilating the cardiogastric sphincter area. As time advanced, it became evident that dilatation by bougienage was not always the answer to the problem and, while the results of such procedures were glowing in the earlier reports, they apparently did not completely relieve, in many instances, the individual's difficulty. In the year 1940, Ochsner and DeBakey[11] reported 3 patients operated upon by a direct approach and gave an excellent review of the literature to that date. The paucity of cases reported from this large clinic would indicate that there was not an extensive amount of direct surgical approach to achalasia of the esophagus being done. At the conclusion of World War II, a revived interest in this problem expressed itself, and there were at that time numerous reports of various operative procedures being carried out to alleviate the obstructive process at the lower end of the esophagus. A long-time follow-up of these procedures, which, at that time, were mainly those following the pattern of Wendel and Heyrovsky, were not actually reported by the original authors, but a very definite swing to the Heller type of operative approach would lead one to believe that the results were really not as good as those brought forth in the original articles.

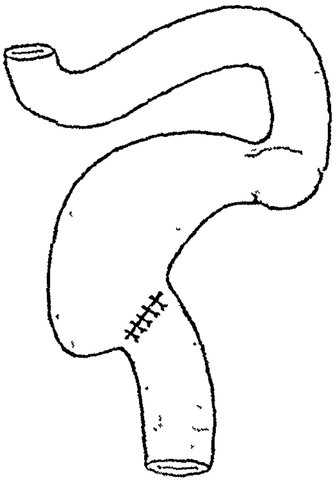

Fig. 1.

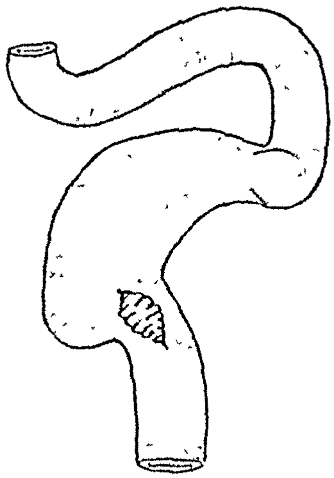

Fig. 2.

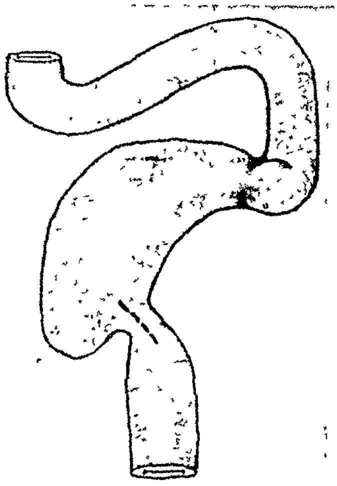

Fig. 3.

Fig. 1.—This drawing shows the line and position of the incision through the muscularis.

Fig. 2.—The incision through the muscularis of the esophagus and the muscularis and the serosa of the cardia of the stomach. The incision is actually somewhat longer than has been depicted by the artist.

Fig. 3.—The extramucosal layers sutured in a transverse direction.

In our own experience during this period from 1945 until 1949, operative procedures in which the entire wall of the esophagus and the stomach were incised and then sutured in a transverse direction, or those in which a side to side anastomosis between the esophagus and the fundus was done, did not give satisfactory end results The incidence of esophagitis was high and, in several instances, ulceration along the suture line led to hemorrhage Two of these were fatal In other patients, it was necessary to break down the anastomosis, resect the lower end of the esophagus, and do an esophagogastrostomy Here too, the results were not good Regurgitation with esophagitis was frequent, and the patient was probably more uncomfortable than before the operation It was because of this, and these unfortunate experiences, that we reverted to the procedure described by Girard in 1915 At the time the first of these were done we were not acquainted with Girard's work

MATERIAL

Such an operative approach has now been carried out on 36 individuals All of these people had had symptoms for a number of years, the longest being approximately 30 years The vast majority, and in the total series during its early period of use had been dilated on either one or numerous occasions Later our thinking has been modified in this direction that regardless of dilatation if the esophagus is large and sigmoid in character such a patient is deemed more suitable for the direct operative approach rather than attempt at bougienage because of the dangers of splitting the esophagus or tearing it in either the introduction of the bougie or from the pressure built up in the various hydrostatic or pneumostatic bags used in this type of dilatation

RESULTS

As was stated above, 36 patients were so operated upon In 33, the results were good, in 2, poor, 2 are dead No classification of "excellent" in the field of results is reported here, because it is the feeling of the authors that no result in esophageal surgery can be considered altogether excellent The classification of "good" has been used to mean that the degree of dysphagia has been markedly or completely removed and that there is no evidence of regurgitation and esophagitis In the 2 individuals classified as a poor result the reason was that there was continued dysphagia in 1 and in the other there was a bothersome reflux esophagitis, which later required further operative procedures, namely, esophageal resection and esophagogastrostomy The end result in the latter case is still a problem The patient still has esophagitis and is, in reality, while still alive some 9 years later, a most unhappy person The first patient classified as poor has had no further operative procedures, but has been followed with bougienage with the mercury filled bougie She does fairly well under this regime A report of the 2 patients who died follows The first died on the tenth postoperative day from a fulminating mediastinitis as a result of perforation of the esophagus some 4 inches above the operative site. The reason for this could never be accurately determined. The second patient actually had an excellent result as far as the operative approach was concerned, but died 2½ years later from a coronary thrombosis. The remaining 32 patients are, apparently, well.

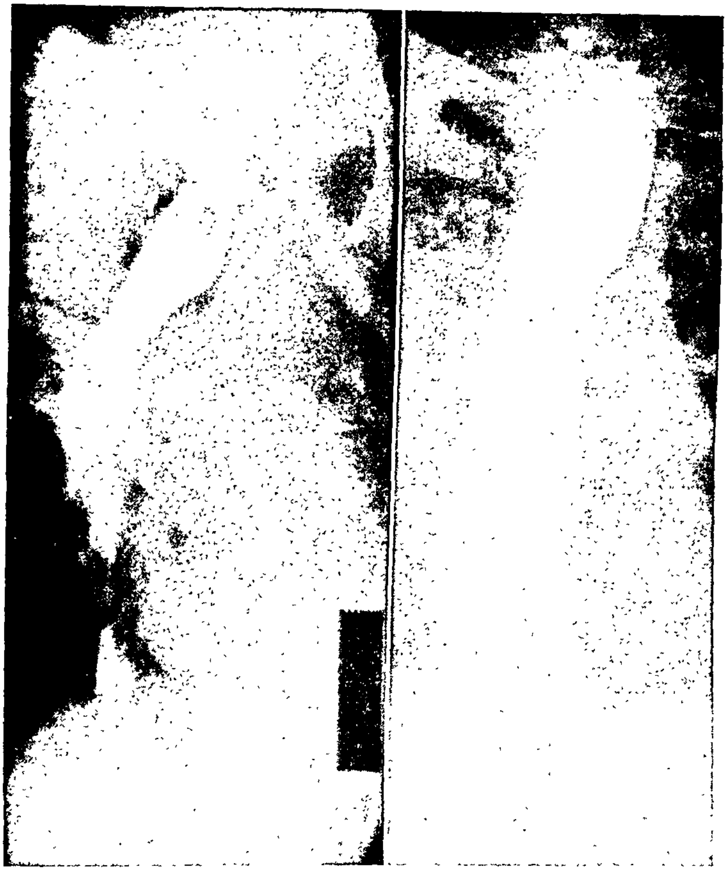

Fig. 4.—The roentgenograms reveal on the right, the preoperative appearance of the esophagus. The postoperative appearance is to the left.

DISCUSSION

The true cause of achalasia of the esophagus, in the thinking of these authors, is still undetermined. Numerous etiological factors have been suggested but in no instance, according to our feeling, have they completely filled the etiological bill. A list of these causes may be seen in Table I. Within recent years, the neurological degeneration theory has seemed the most popular. Still, as regards this theory, there seems to be a rather large amount of disagreement. It has been thought that the degeneration of the plexus of Auerbach is one of the prime causes of the disease, for it has been to the action of this plexus that motility in the lower portions of the esophagus is attributed. Studies of the motility of the entire esophagus have been carried out by the use of air-filled and fluid-filled balloons. It has been demonstrated by Flood[12] and his associates that even in achalasia there is still considerable motility in the lower end of the esophagus as recorded by their readings and by the ability of the esophagus to promote propulsion of the balloon downward On the other hand, Olsen[13] and his associates have felt from their experimental work that the diagnosis of achalasia can be accurately made by the lack of motility in this portion of this organ It well may be that, in those instances in which the esophagus is markedly dilated, the size of the balloon was actually insufficient to stimulate the esophageal wall to contraction It must be further realized that in any study of the wall of a markedly dilated esophagus in which the number of islands of the plexus of Auerbach is counted, that the paucity of the aforementioned may be due to the greatly increased area of the esophageal wall It would appear that there is no way

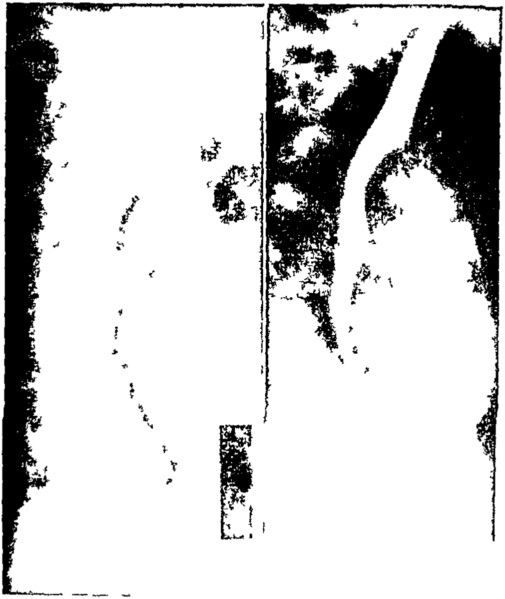

Fig 5—The preoperative appearance of the esophagus is revealed at the left. The postoperative view of the esophagus made approximately 1 year later appears at the right

TABLE I PROBABLE CAUSES OF ACHALASIA

1 Dysfunction of nerve supply
   A Vagal influence
   B Parasympathetic influence
   C Degeneration of plexus of Auerbach
2 Hypertrophy of the cardiac muscle
3 Hepatogastric ligament
4 Compression from other sources

to obviate this error from a statistical standpoint. The only true method is probably that in which it is adequately demonstrated that there has been actual degeneration of the plexus bodies.

In the various patients upon whom we have operated, we have been almost uniformly impressed by the fact that the musculature in the region of the cardiogastric junction is not of normal caliber; in fact, in some instances, it is markedly thickened and has the appearance of the pyloric sphincter in children with pylorospasm. This observation has led us to believe that there is much more to the theory of hypertrophy of the musculature in this area than has been previously credited. It is difficult to justify the presence of a partially atonic muscle above the sphincter and markedly hypertrophied muscle over the sphinctal area on the basis of neurological degeneration. It would seem to us that the reverse is probably true and that the muscle in this area thins out under the pressure of long retained food and mouth secretions, because of a markedly hypertrophied muscle at its lower end.

It was because of these considerations and observations, as stated in the above paragraph, that we felt that an operative approach such as has been used by us would do two things. First, it would allow the sphincter to become open so that deglutition would be possible and comfortable and free from distress; and, second, that sewing the muscle in a transverse direction would cause enfolding of the gastroesophageal mucosa in such manner as to afford a type of sphincter or stop-gap against reflux in this area. The fact that in 35 of the 36 patients there has been no reflux, as demonstrated either by the patient's symptoms or by roentgenologic examination, would lead us to feel that we are correct in our major premise.

Earlier in this article, it was mentioned that it was our feeling that, perhaps, it is unsafe to do dilatation in the presence of a markedly dilated or sigmoid-type esophagus, because the musculature of the esophagus is extremely thin and perforation is, theoretically at least, highly probable. In fact, this thought is borne out by a report from the Mayo Clinic[14] in which there were ten perforations in 550 patients dilated. This, as will be seen, is a perforation incidence of approximately 2+ per cent. With modern techniques, the fatality rate in the direct approach does not approach or exceed this level. Therefore, it has been our practice, when such an individual, namely one with a so-called megaesophagus, is encountered, even though dilatation has never been carried out, to use the direct approach rather than attempt dilatation. In the main, the patient is more satisfied with the result, and I am certain that the physician is as well. We do not mean by the former statements that we are entirely against dilatation, because that is not the case. In those individuals with a moderately dilated esophagus, but in which the esophageal wall appears to be adequate, dilatation can be carried out with a good degree of success. If it fails, then the patient is placed in the group who are thought to be benefited only by a direct approach and this has been carried out. It is an interesting fact that individuals with long-standing esophageal disease are oftentimes not exact when evaluating their own disease They have become so accustomed to having difficulty in swallowing that it becomes like a cross which they are willing to bear and little attention is paid to it It is not, in many instances, until these patients are operated upon and an adequate lumen is established that they for the first time realize the true nature of the difficulties which they have been experiencing for many years It is not uncommon after the adequate lumen has been established to have the patient, of his own volition, volunteer the information that he never realized before what it was to swallow so comfortably

CONCLUSION

1 Thirty six patients with achalasia of the esophagus were operated upon by us from 1949 until 1958

2 Thirty three of these patients have had a good result In 2, the result was poor Two are dead

3 A modification of the Heller procedure has been described and has been used by the authors in the feeling that a pseudosphincter at the lower end of the esophagus is thus established and that regurgitation of gastric secretions and subsequent esophagitis is reduced

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DISCUSSION

DR HENRY L HEIMLICH, New Rochelle, N Y —We have been successfully using a reversed gastric tube for replacing the esophagus In this procedure, which is being shown in detail in the motion picture section of this meeting, a tube is created from the greater curvature of the stomach The tube, which remains attached near the cardia, is reversed in direction, and brought to the neck subcutaneously, retrosternally, or intrapleurally. The gastric tube is anastomosed to the cervical esophagus. Peptic esophagitis does not occur, because the antrum of the stomach, which does not secrete acid, forms the part of the tube that is anastomosed to the esophagus. This has been confirmed clinically in patients followed up to 7 years by Dr. Dan Gavriliu. Microscopic sections through the esophagogastric junction showed no evidence of inflammation in the esophagus in those of my own patients who have died of metastatic carcinoma several months after operation. I would like to suggest that patients with peptic esophagitis or achalasia, when other procedures have failed, and patients with bleeding esophageal varices, may be benefited from esophageal replacement with a reversed gastric tube. In these cases, a shorter reversed gastric tube than that used in the treatment of carcinoma may be the procedure of choice.

DR. MARK M. RAVITCH, Baltimore, Md.—Dr. Tuttle's interesting paper touched on the question of the hiatus which existed for some 30 odd years after Heller's work, until we all again became aware of it through the paper of Barrett and Franklin, some 10 or 12 years ago. Dr. Felix Steichen and I were interested in trying to find the reason for this temporary eclipse of what seems to be a good operation. As Dr. Tuttle said, Gottstein from Mikulicz' Clinic in 1901 suggested the operation, but did not perform it, and it was Girard who actually did perform the first successful extramucosal cardiomyotomies. This Girard of Berne was not, Mr. President, with reference to your remarks of this afternoon, a specialized surgeon. Among other things, he performed two successful hemipelvectomies before anyone else had done so.

We then tried to write to Heller's scientific descendents and were surprised after some time (slide) to get a letter from the Russian Zone from Dr. Heller, who sent this photograph of himself that he was writing from Leipzig, "wo ich doch labe'' using this form rather than "wohne." Dr. Heller said that he had never had any misgivings about the operation, that he had never ceased to perform it and with continually good results, but that he had never been able to convince his own countrymen of its value, whereas the French had taken up the operation at once and had continued to perform it ever since. As Dr. Tuttle and many of you know, Santy of Lyons, D'Allaines of Paris, and his pupil, Lortat-Jacob, have enormous personal series of the Heller operation. They raised the point, and in conversation with Mr. Phillip Allison this point was raised again, that poor results after the Heller procedure, particularly esophagitis, are probably due to the presence of a hiatus hernia, either pre-existing and unsuspected, or one produced in the course of operative manipulation. The French go so far as to suggest that the hiatus should regularly be tightened and that, perhaps, frequently the stomach should be sutured back to the esophagus, reconstructing the acute angle of His.

DR. RICHARD H. SWEET, Boston, Mass.—There is not very much time left at this session so I will confine my remarks to just a few comments. I have used the Heller operation with preeminent success. I have known of Dr. Tuttle's interest in this procedure, the Girard operation. I have not felt, in my experience at least, that I have needed it, because I have not been aware of the results of regurgitation and esophagitis and so on. On the other hand, when we stop to think about it, there are two distinct anatomic types of achalasia of the esophagus; the type of which Dr. Tuttle showed two examples is the type on which I always use the Heller operation. In that type, the lower end of the esophagus is characterized by preeminently thickened, almost sphincter-like, hypertrophied circular muscle. I think, though, that I tend to make an incision through the muscularis even longer than Dr. Tuttle does, and I would be a little fearful about restoring the anatomic relation.

On the other hand, in the other type of achalasia, which is characterized usually by the enormous dilatation of the esophagus with its sigmoid tortuosities, we usually find, as you know, a very thin-walled atrophic distal end proximal to the cardia. (Of course this disease has nothing to do with the cardia whatsoever). In that group, it

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AN AUTOCLAVABLE STATIONARY SCREEN PUMP-OXYGENATOR WITH FILMER

Jerome Harold Kay, M.D. (by invitation), and Robert M. Anderson, M.D. (by invitation), Los Angeles, Calif.

In 1951, Miller, Gibbon, and Gibbon[1] described a pump-oxygenator which consisted of a stationary screen oxygenator and rotary pumps. This apparatus was reported by the authors to perform most satisfactorily. In 1954, Dr. Alfred Blalock suggested to one of us (J. H. K.) that he felt the Gibbon pump-oxygenator would be the most successful apparatus for open heart surgery over the ensuing years. Consequently, in 1955, Kay and Gaertner designed and developed an apparatus using the Gibbon principle of the stationary screen oxygenator and rotary pumps. This apparatus can be seen in Fig. 1.

This first apparatus consisted of four pumps, a coronary-sinus reservoir, venous reservoir, main oxygenator, and a separate arterial filter. Although it performed very well and the chronic survival rate in dogs was 70 per cent, it had several drawbacks. It was a relatively complicated system and because of the four pumps it was difficult for one person to run. If it were possible to decrease the number of pumps, the amount of hemolysis would be less, the running of the apparatus would be easier, and the amount of blood necessary to fill the system would be less.

After several months of work, two of the pumps were eliminated. This was achieved by allowing the coronary sinus blood to drain into the venous

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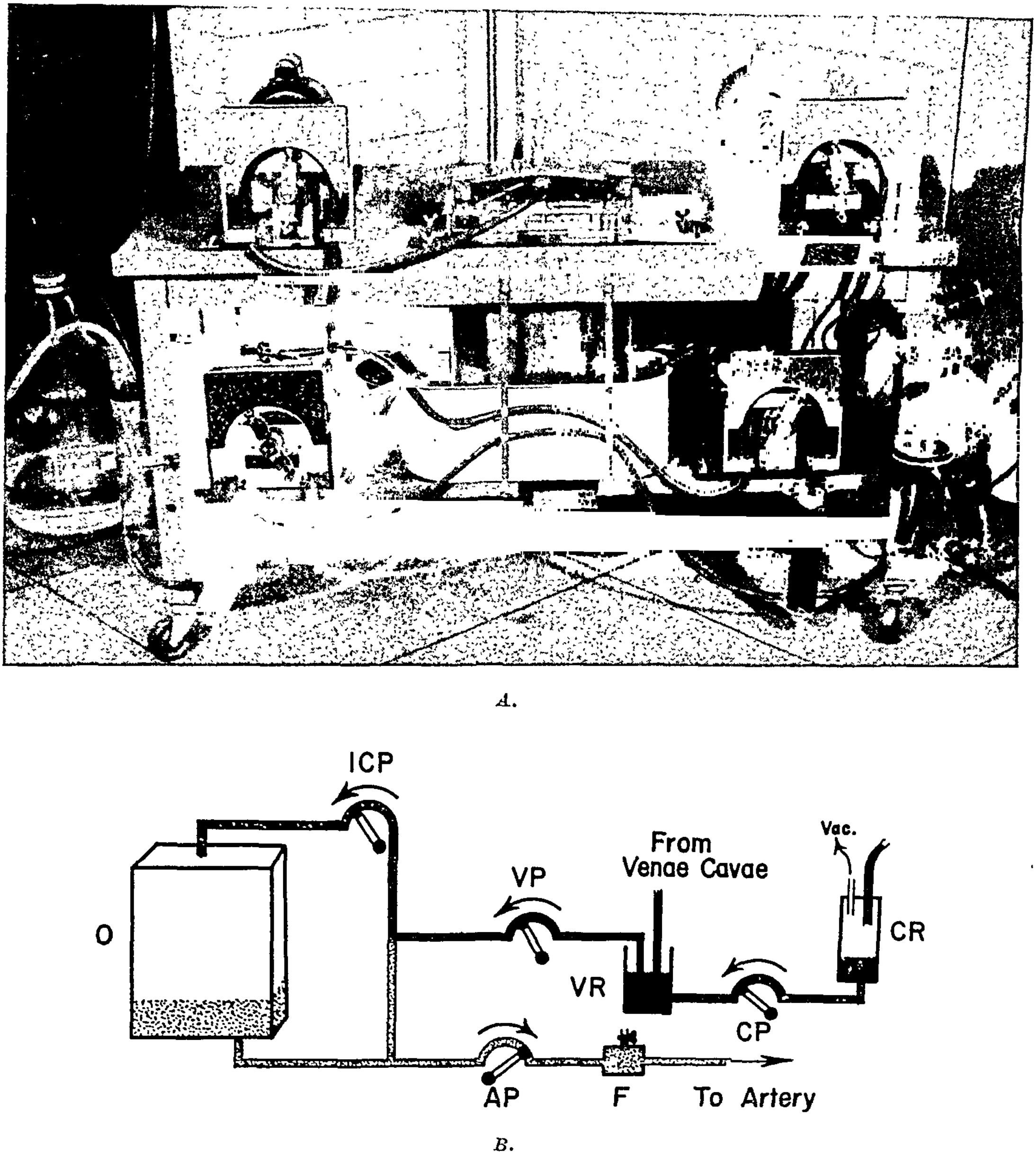
From the Cardiovascular Research Laboratory, Department of Surgery and The Cardiorespiratory Laboratory of the University of Southern California School of Medicine and the Saint Vincent's Hospital, Los Angeles, Calif.

Aided by a grant from the American Heart Association and The Los Angeles County Hospital Attending Staff Association.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

reservoir by gravity rather than by pumping. A second pump could be eliminated by employing a large internal shunt from the bottom of the oxygenator to the venous reservoir. These improvements were made and the apparatus (Fig. 2) became easier to run and the amount of blood for priming was decreased. Although the hemolysis was below 100 mg. per cent in the first apparatus in runs of one-half hour it was even less with the two-pump system. The chronic survival rate of animals with the second apparatus increased from 70 to 85 per cent but this increase in survival rate may have been as much

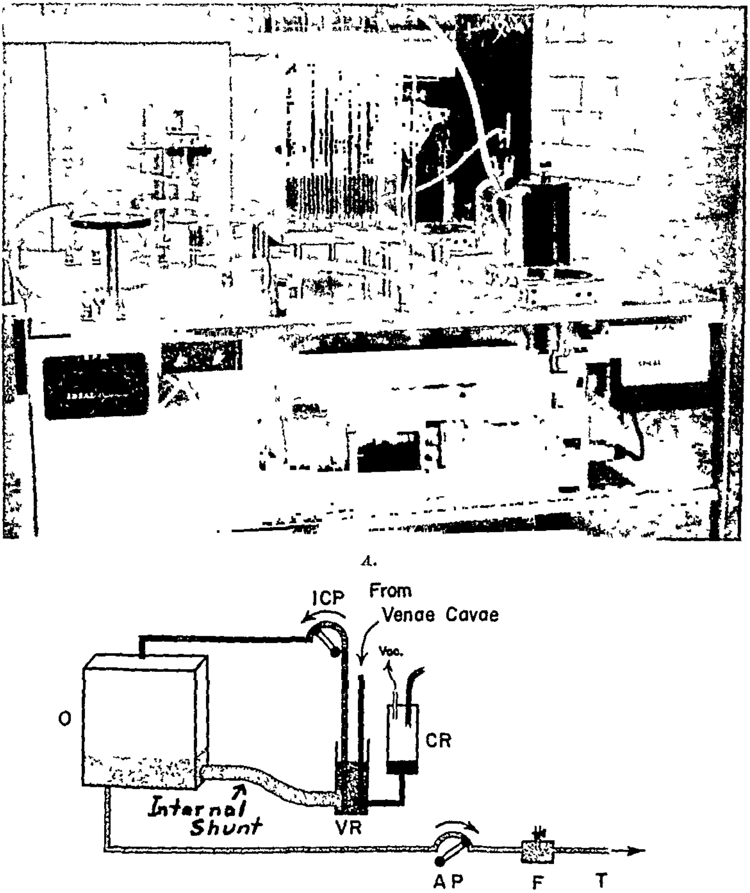


A.

B.

Fig. 1.—*A* and *B* show the first filming apparatus used by Kay and Gaertner. Coronary sinus blood was aspirated from the heart into the coronary reservoir (*CR*). This was pumped into the venous reservoir (*VR*) where it mixed with blood returning from the superior and inferior venae cavae. This blood was pumped by the venous pump into a tube in communication with the arterial reservoir. The internal circuit pump circulated the blood to the top of the oxygenator. It then ran down the stainless steel screens in an atmosphere of oxygen where it became oxygenated. It was then pumped back into the aorta after first being filtered.

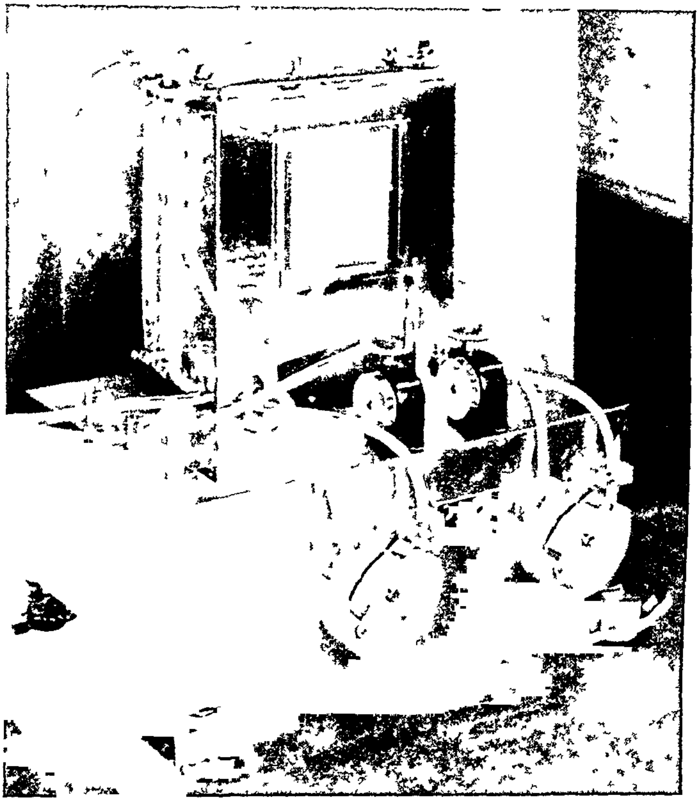
related to our experience in using heart-lung machines as to the improvement of the apparatus. Nevertheless, the second apparatus was a marked improvement of our first model. This apparatus was presented by Kay and Gaertner[2] at The Surgical Forum of The American College of Surgeons in 1957. In this heart-lung machine, gravity drainage was also used to return blood from the animal to the apparatus. This prevented fluttering of veins and other difficulties encountered when blood is pumped from the venae cavae. This technique was used by us early in 1954 and has been continued to the present time.



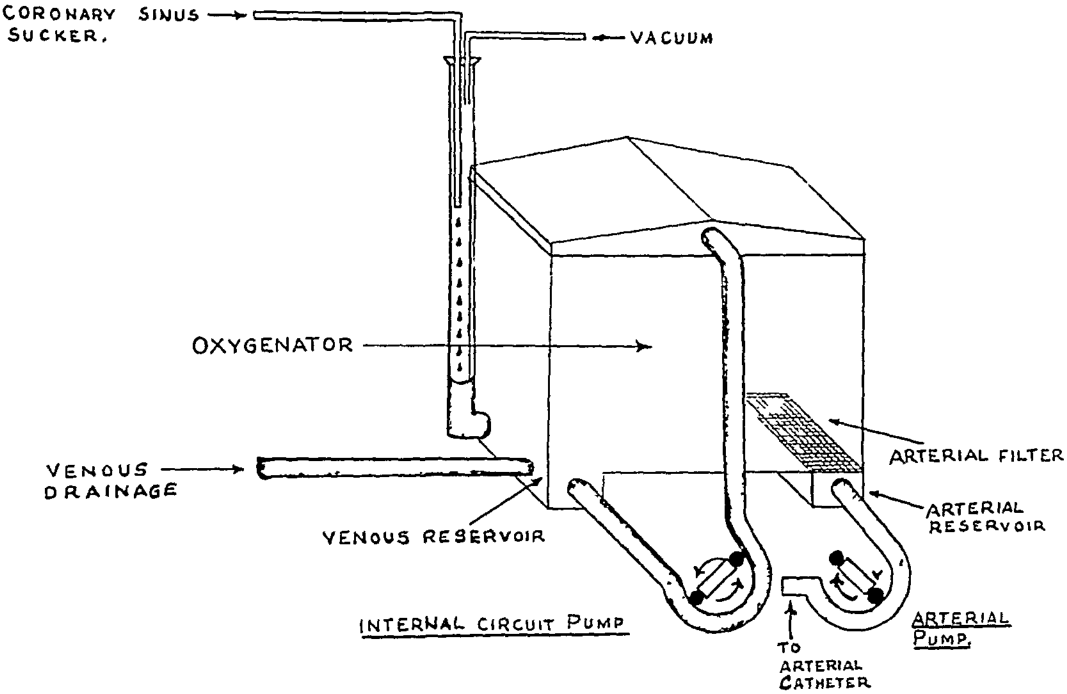
A.

B.

Fig 2.—*A* and *B*. This second apparatus is greatly simplified. Two p eli nated and the priming volume has been decreased



A.



B.

Fig 3 —A and B The third apparatus is further simplified by combining all chambers into one chamber The arterial filter has been moved into the large chamber The oxygenator is autoclavable and there is an automatic filmer

Apparatus No. 2 worked most satisfactorily. However, after many experiments more improvements were made, and pump-oxygenator No. *3* was constructed. This can be seen in Fig. 3. This pump-oxygenator is the result of 3 years of research work with more than 300 experiments employing total cardiac bypass. The apparatus as it is now used was developed in the research laboratories at the University of Southern California School of Medicine by the present authors. It has one common chamber. The separate chambers for the coronary sinus reservoir, venous reservoir, oxygenating chamber, and arterial filter are combined into one chamber. This eliminates the unnecessary connections on the arterial side and decreases the priming volume.

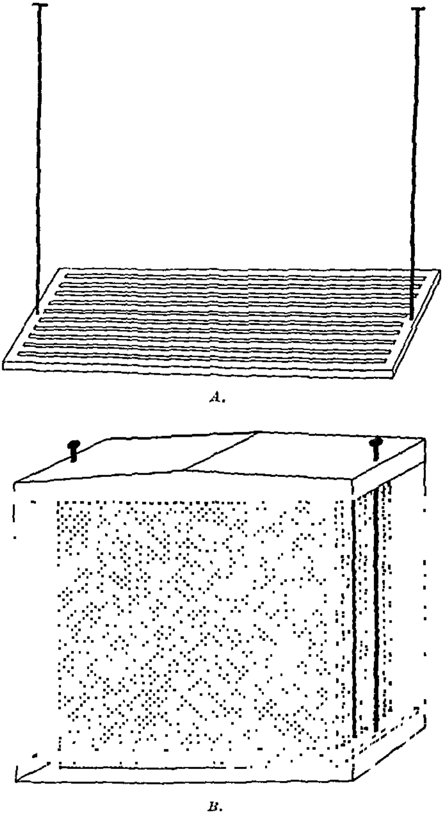
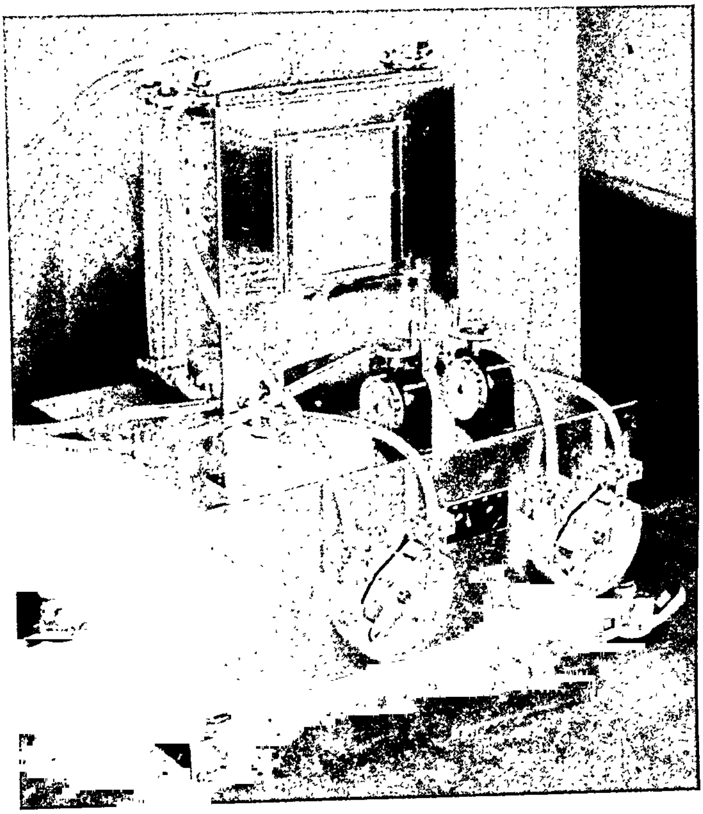


Fig. 4.—*A* and *B* show the automatic filmer. This filmer establishes a film of blood on the screens by simply lowering the filmer.



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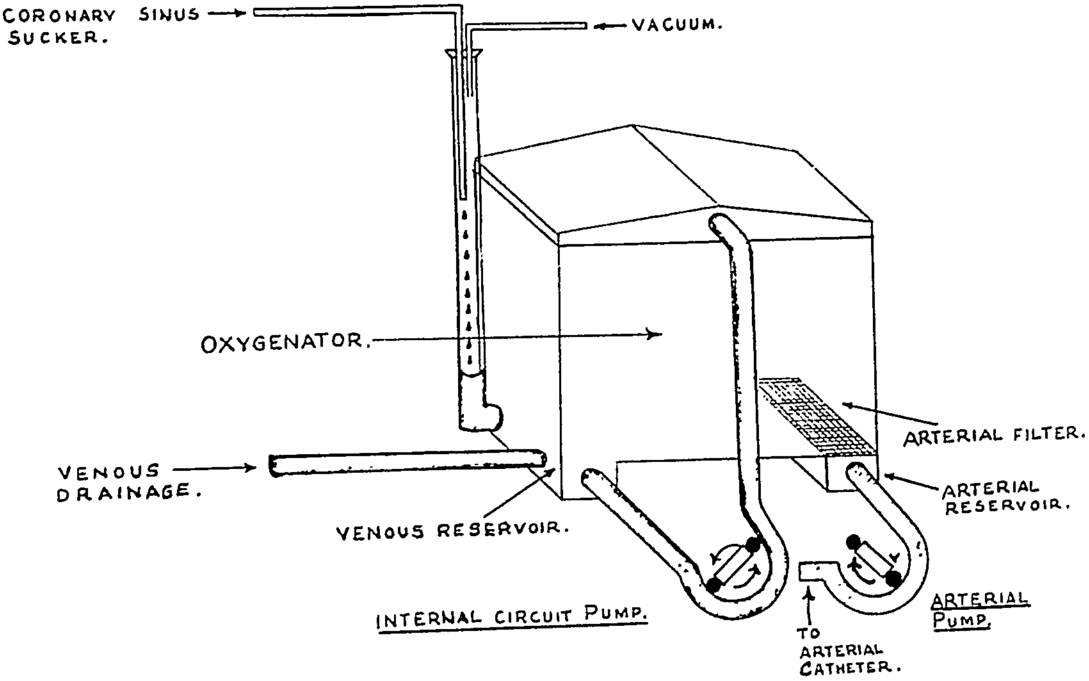

B.

Fig. 3.—*A* and *B*. The third apparatus is further simplified by combining all chambers into one chamber. The arterial filter has been moved into the large chamber. The oxygenator is autoclavable and there is an automatic filmer.

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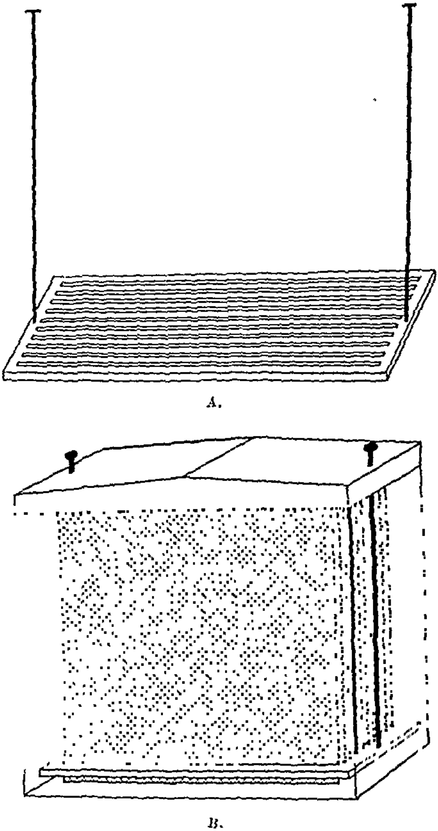

Fig. 1.—*A* and *B* show the *automatic filmer*. This filmer establishes a film of blood on the screens by simply lowering the filmer.

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One of the most important improvements consists of the automatic filmer (Fig. 4). In the first and second apparatuses, a film of blood was established as described by Gibbon and consisted of filling the entire oxygenating chamber containing the screens with saline. This chamber was emptied rapidly of its saline, thereby leaving a film of saline on the screens. As the saline was drained, blood was pumped into the distribution chamber, and this blood rolled onto the screens in a film and replaced the film of saline. The filmer on the third apparatus was first described in 1957 by Anderson, Anderson, and Kay[3] and consists of an autoclavable plastic sheet with slots in it for the screens. The sheet is raised to just beneath the distribution chamber and, as it is lowered, a film is produced on the screens. The new method using the filmer has several advantages: no blood is discarded with the waste saline; blood is not diluted with saline; the method is timesaving and simple.

Our early oxygenators were made of Lucite but since they could not be sterilized by autoclaving, sterilization was a problem. Zephiran was first used for sterilization but this was not satisfactory since it did not destroy all the organisms. Eleven per cent formaldehyde solution as suggested by Kirklin of the Mayo Clinic was used but was difficult to handle. Ethylene oxide gas was next used but this was not practical and also caused crazing of the polyethylene. For this reason a stainless steel oxygenator with completely autoclavable parts was made.* This has greatly simplified sterilization.

The pump-oxygenator No. 3* was described by Kay and Anderson[4] in 1957. It is run in the following manner. Blood is returned from the superior and inferior venae cavae to the venous reservoir by gravity drainage. It is then pumped by way of a roller pump to the distribution chamber at the top of the oxygenator. From there it flows onto a series of stainless steel screens which are suspended from the distribution chamber. Ten liters of 97.5 per cent oxygen and 2.5 per cent CO_2 per minute flow into this chamber and oxygenate the blood. The blood passes through a filter and is pumped into the aorta via the femoral artery or subclavian artery. The speed of perfusion is regulated by the aortic pressure. The apparatus is capable of oxygenating and delivering an amount of blood equal to normal cardiac output in adults and children.

CLINICAL USE

The third apparatus has been in clinical use since Dec. 12, 1957. Since then 14 operations have been done. Twelve of these patients had closure of interventricular septal defects, 1 had complete correction of tetralogy of Fallot, and the remaining 1 had correction of an interatrial septal defect associated with pulmonary stenosis. Only 1 patient died. This was the fourth patient operated upon. In this patient, as well as the first 3 patients, the pericardial flap was closed loosely with four stitches. The patient had been alert and recognized the doctors and his relatives. Although his blood volume was normal, his blood pressure could not be elevated with more transfusions. He died 18 hours postoperatively. At autopsy there was a 2 cm. blood clot completely surrounding the heart and causing death from cardiac tamponade. In the last 10 patients, the pericardial sac has been left open and these patients have all done well. Postoperative bleeding has been minimal, being 150 c.c. to 400 c.c. per patient. All chest catheters are removed 18 hours postoperatively. All patients are alert and awake at the end of the procedure.

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*Kindly constructed for us by Corco, 10418 Venice Boulevard, Los Angeles 34, Calif.

TABLE I. RESULTS OF FIRST 14 CONSECUTIVE CASES OPERATED UPON WITH USE OF KAY-ANDERSON AUTOCLAVABLE HEART-LUNG MACHINE

IVSD	IVSD	IVSD PDA	Died 18 hours IASD IASD postoperatively
IASD PS	TET PDA	IVSD PDA	IVSD
IVSD	IVSD PDA	IVSD	IVSD
IVSD	IVSD		

SUMMARY

The development of an autoclavable stationary screen oxygenator with a filmer has been described. This oxygenator has only one chamber. It is easy to clean, assemble, and sterilize. The pumps are of the roller type with explosion proof motors. The apparatus is easy to use and maintains normal cardiac output during cardiac bypass. All of the blood from within the chest and heart is aspirated and re-used during bypass. This apparatus has been used on 14 patients with no deaths due to the apparatus and only 1 death 18 hours postoperatively due to cardiac tamponade.

We wish to express our appreciation to Mr. Larry Xavier for his invaluable assistance.

REFERENCES

1. Miller, B. J., Gibbon, J. H., Jr., and Gibbon, M. H.: Recent Advances in the Development of a Mechanical Heart and Lung Apparatus, Ann. Surg. 134: 694-708, 1951.
2. Kay, J. H., and Gaertner, R. A.: A Simplified Pump Oxygenator With Flow Equal to Normal Cardiac Output, Surg. Forum 8: 267-271, 1957.
3. Anderson, R. M., Anderson, D., and Kay, J. H.: A Filmer for the Stationary Screen Oxygenator, Surgery 42: 896-897, 1957.
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(For Discussion, see page 530)

COMPARISON OF RELATIVE MERITS OF OCCLUSIVE AND NONOCCLUSIVE PUMPS FOR OPEN-HEART SURGERY

Together with Description of Simple Flowmetering Method for Clinical Use

Paul C. Hodges, Jr., M.D. (by invitation), Richard Cardozo, M.D.***
*(by invitation), Andre Thevenet, M.D.*** (by invitation), and*
C. Walton Lillehei, M.D., Minneapolis, Minn.

THE SELECTION of a pump to replace temporarily the cardiac function during a period of total cardiopulmonary bypass is an important consideration best based upon objective evidence rather than personal caprice. At present, legitimate differences of opinion concerning optimal pumping systems exist among different groups engaged in this work.

We have had extensive laboratory and clinical experience with two types of pumps: a multiple cam-actuated finger pump manufactured by the Sigmamotor Company† and a roller pump manufactured by the Mark Company.‡ Some apparent differences in performance have been noted which seemed worthy of more detailed and objective study.

In order to investigate these observations, we have undertaken a series of controlled experiments aimed at (1) comparison of performance characteristics against known resistances, and (2) evaluation of trauma to the circulated blood.

METHODS OF STUDY

Comparison of Flow Characteristics.—A simple recirculating system (Fig. 1) was set up with four parallel pumps, two of which were of the finger (Sigmamotor) type and two of the roller construction. Each pump was tested independently of the others by occluding the inflow and outflow lines of the pumps not under immediate consideration. The pumps drained a common pair of

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*U. S. Public Health Service Heart Fellowship.

**Research Fellow, U. S. Public Health Service.

***Fullbright Travel Fellowship.

†Sigmamotor, Inc., 3 North Main Street, Middleport, N. Y.

‡Mark Company, 31 West Street, Randolph, Mass.

calibrated reservoirs (Fig. 1) and pumped into a common constant-level reservoir against regulated static pressure maintained by an overflow line draining back into the calibrated reservoir. The pump hoses, lines, and connectors in the parallel circuits were identical. An arterial cannula inserted into the efferent line produced line resistances comparable with those encountered during clinical perfusions (Fig. 1). Mean line pressures were measured with a Statham P23D strain gauge and Sanborn direct writing recorder at a point just proximal to the cannula. Flow was measured as the rate of fall in the calibrated reservoirs.

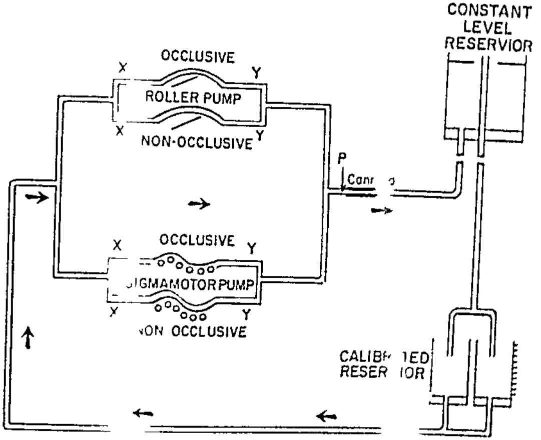

Fig. 1.—System for c [illegible] rison of Flow Characteristics. [illegible] studied independently by [illegible] on of inflow and outflow lines [illegible] of the four pumps can be [illegible] and Y. Line pressure is [illegible] red at point *P* with a Statham [illegible] other pumps at points X [illegible] is measured as the rate [illegible] in the calibrated reservoirs. T [illegible] strain gauge, and flow [illegible] be varied in height to ot [illegible] hydrostatic resistance comparab [illegible] nstant-level reservoir can [illegible] the cannula (catheter) s [illegible] rted to simulate clinical conditi [illegible] systemic resistance and

A finger pump ([illegible] amotor TM-2)[1] with plates [illegible] ne side set occlusively and on the other side [illegible] occlusively,* a roller pump [illegible] k II) set occlusively, and a similar roller [illegible] p set nonocclusively were used. In both types of pumps, the total occlu [illegible] was obtained by careful adjustment of the pumping cams so that the app [illegible] mation of the walls of the pump hose would be just complete at the heigh [illegible] f the stroke. This type of careful adjustment is very important in respect [illegible] prevention of mechanical breakdowns and reduction of blood trauma. Eq [illegible] nonocclusion was achieved by reducing occlusion so that flow of 1,500 c.c. [illegible] er minute was obtained from the same pump capable of an output of 2.000 c.c. when set occlusively. The hydrostatic colu [illegible] the constant-level reservoir (Fig. 1) was set at [illegible] 70 cm. of [illegible] cover the physiologic range of mean aortic pr [illegible]

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*In this study the term nonocclusive is used to [illegible] roller set partially occlusive to the degree [illegible]

Comparison of Evidence of Blood Trauma.—For this portion of the study 2,000 c.c. of freshly drawn heparinized dog blood was pooled and equal aliquots (500 c.c.) were simultaneously recirculated through each of the four pumps utilizing separate but identical circuits with the pump settings as described for use in the comparison of flow characteristics. The blood samples for determinations of plasma hemoglobin, fibrinogen, and platelets were drawn in oiled syringes. The method of Flink[2] was used for measurement of plasma hemoglobin. For fibrinogen the method of Kjell-Jacobson[3] was utilized.

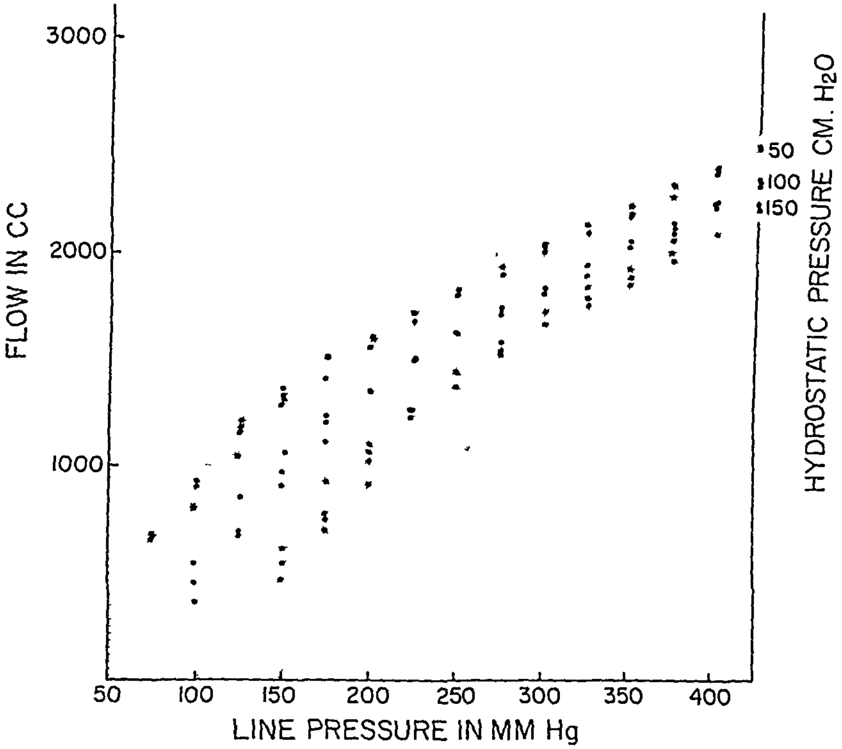

Fig. 2.—Graphic Representation of Data on Flow Characteristics Categorized in Detail in Table I. Flow is charted as a function of line and hydrostatic head pressure. The individual dots are representative of three determinations, each type pump was studied both totally and partially occlusive under the prescribed pressure conditions. There were no significant differences in flow rates related to type of pump or degree or occlusion as long as the line pressures developed were the same.

Group I: A series of three experiments were undertaken in which blood was recirculated through each of the four pumps at 1,500 c.c. per minute for 2 hours and through identical No. 14 Fr. Bardic catheters,* 15 cm. in length. One-half inch internal diameter latex rubber pump hose, ¼ inch internal diameter polyvinyl (Mayon†) connecting tubing, and reservoirs of 2 inches internal diameter polyvinyl tubing (Mayon) were used.

Group II: A series of three experiments in which conditions were identical with Group I except that ¾ inch internal diameter latex rubber pump hose was used in the finger pumps and reservoirs were 1½ inch internal diameter polyvinyl.

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*Bardic Cardiovascular Catheter (No. 1055), C. R. Bard, Inc., Summit, N. J.
†Mayon Plastics, 415 17th Avenue North, Hopkins, Minn.

GROUP III A series of three experiments which were similar to Group II except that No 16 Fr Bardic cannulas, 15 cm in length, were utilized and the connecting tubing used was of 3/8 inch internal diameter instead of 1/4 inch

RESULTS

Comparison of Flow Characteristics—Under these conditions of comparable resistances the flow rates of the four pumps were virtually identical at any given line and hydrostatic pressure (Table I and Figs 2 and 3)

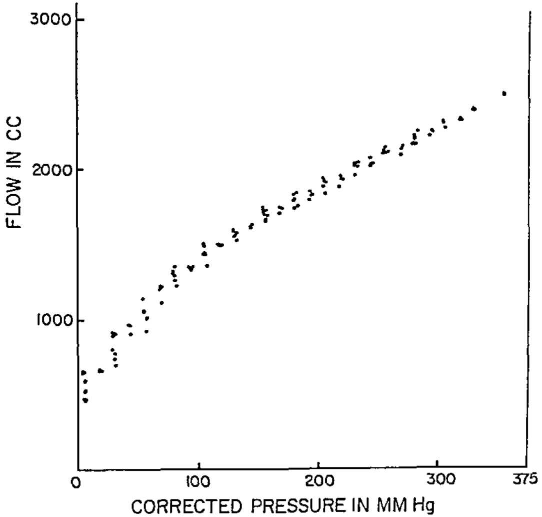

Fig 3 —Flow Is a Function of Pressure Gradient Across the Cannula The corrected line pressure for each of the four pumps was obtained by subtracting hydrostatic resistance from the line pressure as recorded in Table I A No 14 Fr Bardic catheter 15 cm in length was used throughout Flow was proportional to the pressure drop and type of pump or degree of occlusion made no difference

There were no appreciable differences in output between roller and finger pumps and no differences in the individual pumps on the basis of presence or absence of total occlusion as long as the line pressures developed were comparable

With an increase in hydrostatic head pressure there was a definite drop in output when line pressure was held constant by regulation of pump speed This drop was present in all of the four pumps tested and was of similar magnitude in each (Fig 2) However, if hydrostatic head pressures were raised and pump speed unchanged, the nonocclusive pumps tended to maintain a constant line pressure with a proportional drop in output whereas the occlusive pumps maintained constant output with a proportional rise in line pressure This is the fundamental difference between occlusive and partially occlusive pumps

When flow was plotted against the pressure fall across the cannula (Fig. 3), it was apparent that flow was a direct function of this pressure gradient. An increase of hydrostatic pressure resistance at the outflow of the system would not affect flow as long as line pressure was raised comparatively. Thus, it is clearly evident that the capacity of any pump to maintain flow against an increasing resistance is directly proportional to the line pressure capable of being developed by that type of pump.

TABLE I. COMPARISON OF PERFORMANCES BETWEEN SIGMAMOTOR AND ROLLER PUMPS EACH WITH TOTAL AND PARTIAL OCCLUSIVE SETTINGS UNDER IDENTICAL CONDITIONS OF RESISTANCE
FLOW C.C./MIN.*

CONSTANT-LEVEL RESERVOIR CM./H_2O	SIGMAMOTOR TM-2						MARK II					
	OCCLUSIVE			NONOCCLUSIVE			OCCLUSIVE			NONOCCLUSIVE		
	150	100	50	150	100	50	150	100	50	150	100	50
Line Pressure												
425	2250	2340		2185	2370		2215	2340	2500	2210	2340	2500
400	2115	2250	2400	2095	2220	2400	2100	2250	2400	2115	2250	2400
375	2020	2160	2280	1960	2100	2320	2025	2145	2320	2070	2145	2320
350	1930	2040	2190	1840	2025	2220	1886	2070	2190	1930	2040	2190
325	1760	1950	2130	1740	1890	2130	1790	1950	2100	1840	1950	2115
300	1690	1830	2025	1650	1800	2025	1660	1830	2040	1720	1830	2040
275	1520	1740	1905	1565	1710	1890	1550	1725	1935	1582	1740	1935
250	1360	1620	1800	1425	1620	1800	1440	1620	1830	1435	1620	1830
225	1220	1500	1680	1250	1500	1740	1257	1500	1710	1235	1500	1755
200	908	1350	1560	1053	1350	1590	1100	1350	1590	1070	1335	1590
175	690	1200	1425	730	1200	1500	903	1230	1500	768	1110	1500
150	460	900	1290	463	960	1350	600	1050	1320	533	880	1305
125		675	1050		680	1170		840	1200		680	1150
100		450	800		360	920		540	920		360	900
75			660			660			660			660

*Each reading in table represents an average of three determinations utilizing the described circuit (Fig. 1) and No. 14 Bardic catheter, 15 cm. in length.

Comparative Studies Upon Blood Trauma.—

Platelets: Early studies of platelet counts on pooled dog blood showed such low initial levels that attempts to estimate disappearance rates were of necessity abandoned.

Fibrinogen: There were no significant differences found in the fibrinogen levels of the various samples studied (Table II).

Plasma hemoglobin: Study of hemolysis rates brought out several interesting factors.

TABLE II. PLASMA FIBRINOGEN—GM. %

PUMP TYPE	0 HR.	1 HR.	0 HR.	1 HR.	0 HR.	1 HR.	0 HR.	1 HR.	AVERAGE 0 HR.	AVERAGE 1 HR.
Roller										
Occlusive	.08	.12	.19	.09	.06	.07	.12	.19	.11	.11
Nonocclusive	.03	.03	.18	.14	.01	.08	.11	.14	.08	.09
Finger										
Occlusive	.06	.09	.10	.12	.03	.07	.11	.15	.07	.11
Nonocclusive	.10	.14	.05	.11	.03	.09	.1[illegible]	--	.08	.11

In Group I (Table III) where the stroke volume of the roller pump was 27 c c as against 17 c c for the finger pump and line pressures were maintained at 275 mm Hg at flow rates of 1,500 c c through No 14 Fr Bardic cannulas without any superimposed hydrostatic resistance, the average hemolysis measured in milligrams per cent under these conditions was substantially lower for the roller pump (set either occlusive or nonocclusive) than for the finger pumps

TABLE III PLASMA HEMOGLOBIN VALUES—MG %*

	GROUP I (HOURS)					GROUP II (HOURS)					GROUP III (HOURS)				
PUMP TYPE	0	½	1	1½	2	0	½	1	1½	2	0	½	1	1½	2
Roller															
Occlusive	11	22	26	56	69	13	71	102	185	251	2	27	45	61	84
Nonocclusive	12	20	27	47	53	10	54	117	103	233	5	20	51	71	96
Finger															
Occlusive	7	90	189	264	292	10	39	83	115	113	6	27	50	71	99
Nonocclusive	10	60	98	160	209	10	46	82	117	141	4	10	34	48	76
Stroke volume															
Roller	27 c c					27 c c					27 c c				
Finger	17 c c					40 c c					40 c c				
Line pressure	275 mm Hg					275 mm Hg					200 mm Hg				
Tubing	¼ in I D					¼ in I D					⅜ in I D				
Catheter	No 14					No 14					No 16				

*Hemolysis (mg %) Produced by the Four Pumps Under Various Conditions The longer effective pumping area of the roller pump (23 cm) as compared to 14 cm (TM 2) gives it a greater stroke volume for any given size pump tubing Differences in hemolysis were directly related to differences in stroke volume rather than to inherent differences in pump characteristics or to occlusion or nonocclusion

In Group II (Table III) where the roller pump stroke volume was kept at 27 c c while the stroke volume of the finger pump was increased to 40 c c by use of ¾ inch internal diameter pump hose The average hemolysis was significantly lower for the finger pumps (set either occlusively or nonocclusively) than for the roller pumps

In Group III (Table III) the effect of a larger catheter in lowering the line pressure and reducing hemolysis is evident

Carefully approximated total occlusion as compared to partial occlusion resulted in no significant differences in rate of hemolysis either for the roller or the Sigmamotor pumps (Table III)

DISCUSSION

In one sense this study was unnecessary because it has been shown, in the systems studied that flow response is in accordance with certain well established and predictable hydrodynamic principles In another sense, however, the study has been very valuable to us, and perhaps to others, in delineating in a clear manner those principles that are of importance

Moreover, a simple but reliable and effective method for accurate measurement of flow rates applicable to clinical perfusions has been developed based upon these hydrodynamic observations (as outlined below)

In any system of known resistance, any pump, regardless of design or presence or absence of total occlusion, which will create a given pressure, will produce the same flow as any other pump in that system at the same resistance (Fig. 4).

In addition, it has been shown that under the conditions of this study, which were set up to simulate clinical perfusions, hemolysis is primarly a function of stroke volume, pump speed, and line pressure and was independent of pump design and the presence or absence of total occlusion. In turn, line pressure is a function of the flow rate desired, the size of the arterial cannula, and the aortic pressure. Pump speed is, of course, a function of stroke volume. Thus, there was no consistent difference in the hemolysis produced by the nonocclusive and carefully approximated occlusive pump of comparable stroke volume. McCaughan and associates,[4] in their study comparing rates of hemolysis caused by a totally occlusive Sigmamotor pump and a totally occlusive roller pump, failed to appreciate that stroke volume is the most significant factor in causation of hemolysis.

PUMP	LINE PRESSURE	CANNULA	FLOW/MIN.
Finger Occ	*Same*	*Same*	*Same*
Finger Non Occ	"	"	"
Roller Occ	"	"	"
Roller Non Occ	"	"	"

Fig. 4.—Flow Is a Function of Pressure and Resistance (the Pressure Gradient). The type of pump used to propel the fluid and its degree of occlusion is important only in that it be capable of producing the necessary line pressure.

Even before this study clarified some of the physical factors contributing to hemolysis, it was suspected for several reasons that the arbitary allegation that "occlusive pumps are more traumatic" was not based upon objective observations. First, upon the basis of logic, it would seem that the single red cell is rather minute, lubricous, and resilient to be consistently caught and crushed by the cam of a carefully adjusted occlusive pump. Moreover, the levels of plasma hemoglobin,[1, 5, 6] measured in our clinical patients perfused with an occlusive pump, have consistently been very low. In clinical perfusions, of course, the final hemolysis level reflects other factors as well, such as length of perfusion, the oxygenator, the coronary sinus blood returned, and the accuracy of blood matching. These other sources of plasma hemoglobin notwithstanding, DeWall[6] found in an analysis of 350 consecutive clinical perfusions, utilizing a Sigmamotor occlusive pump and the helix reservoir bubble oxygenator with some pump runs lasting up to 2 hours, the mean plasma hemoglobin value was under 70 mg. per cent and the highest value ever recorded (155 mg. per cent) was far below the level of 3,700 mg. per cent estimated by Flink[7] as necessary to cause renal damage.

No data could be obtained of the effect of these pumps upon the rate of disappearance of platelets under controlled conditions because of the very low initial levels in the pooled canine blood. However, data previously presented from this clinic[5, 6] upon the effects of extracorporeal circulation on the platelets in man, utilizing an occlusive pump (Sigmamotor) and helix reservoir bubble oxygenator, indicate that platelet destruction is not a problem in clinical perfusions lasting up to 2 hours and consequently we no longer routinely measure this entity in our patients.

While the pressure-flow characteristics of nonocclusive pumps conform to the same curve as do occlusive pumps, their lower efficiency, as expressed in terms of increased pump speed and greater flow instability in the face of variations in systemic resistances, can limit their usefulness in clinical perfusions by making it more difficult to maintain a desired output at all times. This value of using an occlusive pump as a flow metering device was appreciated early in the cross circulation work.[8]

A Suggested Flowmeter for Use in Open-Heart Surgery.—It may be logically argued that using a carefully calibrated occlusive pump, together with continuous monitoring of the patient's systemic blood pressure and electroencephalogram, makes a flow meter within the extracorporeal circuit superfluous during perfusions. In our experience this appears to have been true. However, it is equally obvious that an ideal flowmetering device which in no way interfered with blood flow or damaged blood elements and which was simple and practicable would be of value as an additional safeguard for the patient.

Such an ideal flowmeter has come out of the data obtained in these studies and constitutes nothing more than the application of Bernoulli's principle and Poisseuille's law to resolve the problem. A calibration curve may be constructed for any type pump, whether occlusive or nonocclusive, with a series of the commonly used arterial cannula sizes such that for a particular pressure drop in the arterial line the flow is known. During clinical perfusions one need simply pick the calibration curve for the size cannula used, subtract the mean aortic pressure from the pressure developed in the line, and determine the flow at any time during the perfusion. Inasmuch as a continuous recording of the arterial pressure is recommended as a routine procedure[1] in clinical perfusions, the only additional measurement needed to determine flow is a line pressure monitor.

Choice of Pump for Clinical Perfusions.—The importance of knowing exactly what the flow rate is at all times is obvious and, thus, for clinical work an occlusive type pump is favored. The stroke volume should be made as large as practicable by use of larger hoses within the pump than for conducting blood to and from the patient. The dimensions in relationship to patient size that we have found useful for these various components of the extracorporeal circuit have been outlined elsewhere.[1] In investigations carried out several years ago,[9, 10] it was found that pure gum rubber was superior to any plastics then available for use as the pump hoses. This still appears to be true.

SUMMARY AND CONCLUSIONS

1. Sigmamotor and roller-type pumps, set both occlusively and nonocclusively, were compared under controlled conditions for ability to maintain flow against resistance and evidence of blood trauma.

2. It has been shown that flow in a circuit is a direct function of line pressure and resistance in accordance with basic hydrodynamic principles.

3. No significant differences in outputs were found between roller and Sigmamotor pumps on the basis of presence or absence of total occlusion, as long as the line pressures developed were comparable.

4. Since flow is a function of the pressure drop across the circuit, it is feasible to measure flow accurately during clinical perfusions by the simple method described.

5. Hemolysis is a direct function of stroke volume rather than design of pump or presence or absence of total occlusion in these pumps studied.

6. No significant change in fibrinogen level was noted during recirculation of blood.

7. The ability of totally occlusive pumps to maintain stable flow in the face of considerable variations in systemic resistance indicate their advantage over partially occlusive pumps in clinical perfusions.

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(For Discussion, see page 530)

CARDIAC BYPASS WITHOUT ARTIFICIAL OXYGENATION

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Our earlier experiences in biologic oxygenation have stimulated us to develop a clinically applicable cardiac bypass procedure using autogenous lung oxygenation.[1-3] Previous experimental work using the pulmonary circulation for oxygenation has been reported. Cohen and Lillehei and their associates[4, 5] obtained oxygenation with perfusion of a single lung. Our experience, including a clinical trial in 1949, leads us to believe that the rapid development of venous obstruction in the isolated lung makes this impractical. Wesolowski and Welch[6] perfused both lung fields using a simple left atrial cannula for aspiration of the venous return. We found, both in our experiments and in a clinical case, that mitral valve occlusion was essential for a dry operative field in the presence of a septal defect. Sirak and co-workers[7] attempted to ensure the latter with a manually retained diaphragm. This has proved to be unreliable in our hands.

We have felt that for effective clinical application of any procedure using autogenous lung oxygenation, the following criteria must be established. Adequate oxygenation and other blood gas exchanges must be obtained by a total pulmonary perfusion and the elimination of any possibility of pulmonary venous obstruction. At the same time a dry cardiotomy exposure should be assured by blocking the mitral valve.

DESCRIPTION OF EXPERIMENTS

Mongrel dogs, weighing 9 to 16 Kg., were anesthetized with intravenous Pentothal sodium and intubated for intermittent positive pressure, controlled respiration on a closed anesthetic circuit; CO_2 absorber was used. Bilateral thoracotomy was performed through the fourth anterior intercostal spaces. In acute experiments, exposure was supplemented by a transsternal incision. Animals were heparinized (1 to 1½ mg. per kilogram intravenously) and polyethylene catheters introduced into the internal mammary artery and

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femoral vein for monitoring systemic pressures. Cannulations* were then performed. A stainless steel cannula was introduced into the femoral artery for peripheral arterial perfusion. The specially designed pulmonary artery cannula of stainless steel (illustrated in Fig. 1) was introduced through an incision just proximal to the bifurcation of the main pulmonary artery and held in place by a previously inserted purse-string suture. This cannula has a slightly bulbous basket tip permitting its retention in the artery with greater security and without excessive irritation to the vessel wall. The vanae cavae were next cannulated with appropriate Bardic catheters, the superior vena cava via the azygos vein, and the inferior vena cava through the right auricular appendage. The cavae were encircled by tape tourniquets. Pulmonary venous return was cannulated from the left atrium using the stainless steel cannula especially designed and illustrated in the accompanying figure. The atrial end of this cannula is gently curved and provided with three side openings to ensure an unobstructed flow. Several ridges were incorporated on the outside of this end for secure gripping by a purse-string suture in the auricular appendage. The side arm retains the balloon-tipped end of a cardiac catheter when not in use, ensuring unobstructed flow through the main channel of the cannula. A rubber sheath forms an air-tight seal at the opening to the side arm around the catheter. The balloon-tipped catheter is fashioned from a conventional single-lumen woven cardiac catheter (size F5 or F6) to the end of which is attached a balloon of highly elasticized rubber which permits a small collapsed structure to be greatly distended when necessary. By appropriate direction of the end of the atrial cannula and with cardioplegia, the balloon-tipped catheter could be passed out of its side arm down the cannula and through the mitral orifice into the left ventricle. The bypass system was completed by connecting the various cannulae to the cardiac pump with disposable heat-sterilized Tygon tubing.† The complete bypass circuit is illustated in the accompanying diagram (Fig. 1). Venous drainage from either side of the heart is by gravity to open reservoirs of Tygon cylinders. Arterial outflow occurred from the most dependant portion of the reservoir with venous filling occurring at a slightly higher level. We found that this arrangement adequately obviated any danger of air embolism and reduced the effects of turbulence. The reservoirs were calibrated for estimation of flow rates. Controlled temperature water jackets encased the reservoirs to prevent excessive cooling during bypass procedures. The extracorporeal circuit was primed with 1,000 c.c. of heparinized (18 mg. per 500 c.c.) donor blood.

Cardiac bypass was commenced by first excluding the right ventricle and right atrium. The caval tourniquets were tightened and the pump flow rate adjusted to deliver the total vena caval return into the pulmonary artery. Adjustments were made until a stable level was obtained in the right reservoir. The left side of the heart was then bypassed by commencing the systemic inflow into the femoral artery and releasing the clamp from the left atrial tubing.

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*Cannulae manufactured by The J. F. Hartz Company, Toronto, Canada.
†U.S. Stoneware; Plastics and Synthetics Division, Akron, Ohio.

Flow rates were once more adjusted, this time to maintain the normal systemic blood pressure. It was found that if systemic pressure was used as the indicator of left pump flow rate, ideal perfusion was obtained and the balance between left atrial return and systemic arterial inflow was automatically stabilized. Once the ideal systemic pressure had been attained the extracorporeal circuit could most effectively and simply be controlled by reversing any deviations in the left reservoir level with minor adjustments to the right pump flow rate, so ensuring a constant systemic perfusion rate without danger of under or overperfusion. Accurate replacement of incisional and other blood losses was returned to the right heart reservoir.

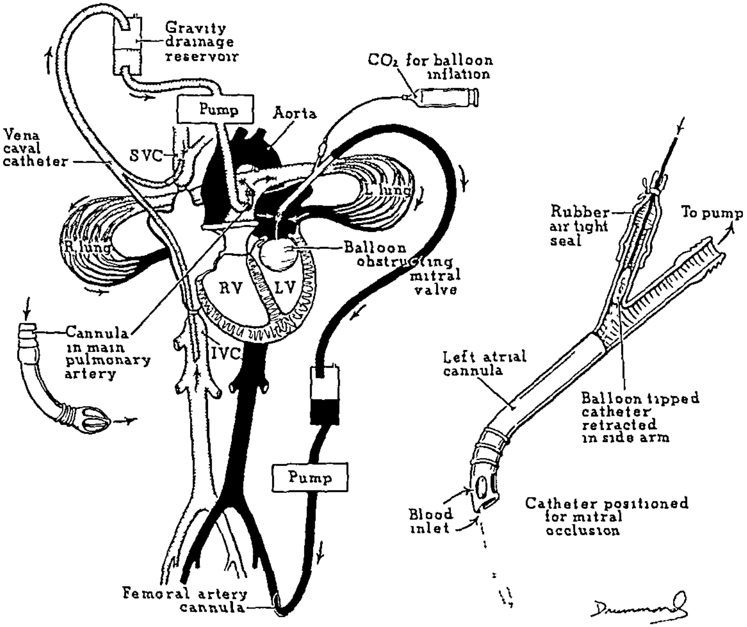
Gravity drainage reservoir
CO₂ for balloon inflation
Pump
Aorta
Vena caval catheter
SVC
L lung
R lung
Balloon obstructing mitral valve
RV
LV
Cannula in main pulmonary artery
IVC
Pump
Femoral artery cannula
Rubber air tight seal
To pump
Left atrial cannula
Balloon tipped catheter retracted in side arm
Blood inlet
Catheter positioned for mitral occlusion
Drummond

Fig. 1.—Diagram of bypass circuit with illustrations of cannulae

An accurate measurement of perfusion flow rates could be taken by temporarily clamping the arterial outlet of the right reservoir for a specified period and measuring the rise in the venous reservoir. No attempt was made at presetting the flow rates of the cardiac pump. In a few experiments, presetting flow rates compared with flow rates obtained during bypass made it obvious that the former was totally unreliable.

The aorta and pulmonary artery are now cross clamped proximal to the pulmonary arterial cannula and asystole obtained by injection of potassium citrate into the proximal aorta. With all outflow tracts occluded, the only escape for pulmonary venous return is by way of the left atrial cannula, even in the presence of septal defects. Minor adjustments to pump rates are then made to accommodate these changes. Occlusion of the mitral valve is performed preparatory to cardiotomy. The curved end of the atrial cannula is directed toward the mitral valve and the catheter gently introduced into the flaccid left ventricle where it could be palpated. The balloon is inflated until felt to be just larger than the mitral annulus, using carbon dioxide to obviate any dangers of coronary air embolism in the event of leakage. The distended balloon is then securely retracted against the mitral annulus and held there by tying down a tape ligature placed around the rubber sheath on the cannula's side arm. Right cardiotomy and septal incision demonstrates a dry field. The balloon is deflated and retracted once more into the side arm of the cannula. The myocardium is resuscitated by removing the aortic cross-clamp, allowing coronary perfusion. When an active cardiac impulse is established, gradual decannulation is commenced in the same order as cardiac bypass was instituted. Vena caval tourniquets were released and first one and then the other vena caval catheter removed as the heart tolerated the increased load. Simultaneous adjustments were made to the right portion of the bypass pump as more blood was allowed to pass through the heart and less drained into the extracorporeal reservoir. Thus, with removal of the second caval catheter, the pulmonary arterial pump could be discontinued and the pulmonary artery cannula removed tying down the purse-string stay suture for effective hemostasis. Attention was then directed toward the left side of the heart which was being supported by the extracorporeal circuit. The left atrial cannula was clamped and the systemic arterial inflow gradually stopped. If this was tolerated without significant alterations in blood pressures, the left atrial cannula was promptly removed—once again tying down the purse-string suture for hemostasis.

Heparinization was then neutralized by using an equivalent dosage of Polybrene* which rarely required supplementing at a later stage. When full cardiac activity had been achieved and hemostasis was assured, the pericardium was loosely approximated and chest closure performed in anatomic layers with bilateral water-sealed chest tube drainage. Chest tubes were maintained on constant drainage for 6 to 8 hours followed by intermittent aspiration for a further 6 hours, after which they were removed. Average chest drainage postoperatively amounted to 150 c.c. Further needle aspirations of pleural cavities were not required after removal of the chest tubes. Postoperative blood reactions were serially tested† in the immediate postoperative period (and corrected where necessary with intravenous 5 per cent sodium bicarbonate). Streptomycin and penicillin were given intramuscularly daily for 4 days.

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*Supplied by Abbott Laboratories, North Chicago, Illinois.

†Beckman pH meter, Model G.

RESULTS OF EXPERIMENTS

The results of experiments are given in the accompanying Tables I and II. Eleven long-term survivors were obtained in 15 experiments. The efficiency of oxygenation is evident from the accompanying blood analysis. There was a slight fall in pH immediately on termination of the bypass but the effectiveness of perfusion may be gauged by the prompt spontaneous reversal of this low hydrogen ion concentration in the immediate postoperative period. This would indicate that no significant oxygen debt occurred within the peripheral tissues. We feel rather that the postoperative pH may be attributed to a cooling tendency exhibited by the animals while on the bypass. These results correlate well with the high perfusion flow rates and the maintenance of preoperative systemic pressures, both arterial and venous, during the bypass procedure. Our hemolysis rates were significantly low when compared with donor blood levels in relation to the high perfusion rates. The only limitation

TABLE I. SUMMARY OF FIFTEEN CONSECUTIVE EXPERIMENTS

DOG WT. (KG.)	FLOW (ML./MIN.)	MEAN INT. MAMMARY ARTERIAL PRESS. (MM. HG)	FEMORAL VENOUS PRESSURE (CM. SALINE)	PLASMA HGB. (MG. %)		PLATELET COUNT FALL (%) AFTER 30 MIN. BYPASS	DURATION OF BYPASS (MIN.)	RESULT OF EXPERIMENT
				DONOR	END OF PERFUSION			
15	1,500	130	6-9	18	48	35	35	Survivor
14	1,500	120	7-11	0	32	22	35	Survivor
12	1,200	100	3-6	0	38	25	32	Survivor
12	1,300	110	6-9	40	100	27	30	Survivor
10	1,000	90	6-9	16	48	20	40	Survivor
10	1,100	100	8-10	0	48	35	40	Died 6 days postop.; brain damage
9	1,000	110	9-10	30	80	30	45	Survivor
13	1,200	130	6-9	25	62	25	55	Survivor
16	1,500	110	5-6	12	32	20	40	Died 2 days postop.; rt. vent. thrombus
12	1,100	115	6-9	47	80		45	Died 6 hr. postop.; bronchial plug
14	1,300	100	5-2	50	100		35	Survivor
15	1,400	130	5-8	20	46		36	Survivor
13	1,200	120	6-8	24	55		42	Survivor
16	1,400	130	4-7	15	38		40	Died 2 days postop.; cause not determined
15	1,800	110	5-8	12	40		36	Survivor

to perfusion flow rates appeared to be those dictated by the pumps' capacity, the size of the tubings and cannulae, and the blood pressure developed. We have used both the Cowan[8] pump and the Lillehei Sigmamotor pump* with equal facility but feel that the former was better able to cope with the high flow rates developed by this system. The ease with which the extracorporeal circuit could be controlled was noted by all operators.

TABLE II. ACID-BASE AND OXYGENATION* RESPONSES TO TOTAL CARDIAC BYPASS

MIXED ARTERIAL O_2 SATURATION			ARTERIAL BLOOD pH			MIXED VENOUS BLOOD O_2 SATURATION		
PRIOR TO BYPASS	AFTER 5-MIN. BYPASS	AFTER 30-MIN. BYPASS	PRIOR TO BYPASS	AT END OF BYPASS	3 HR. AFTER OPERATION	PRIOR TO BYPASS	AFTER 5-MIN. BYPASS	AFTER 30-MIN. BYPASS
100	100.5	100.5	7.35	7.45	7.36	—	—	—
98	97.5	101	7.45	7.30	7.30	—	—	—
100	85	95	?	7.35	7.43	56	60	65
86	103.5	103	7.58	7.60	7.40	28	38	52
85	105	105	7.40	7.43	7.45	45	65	70
103	103	102	7.49	7.36	7.40	43.5	61	64
102	98.5	96	4.42	7.39		70	80	80
103	104	104	7.45	7.30	7.33	41	80	76
103	93	100	7.40	7.58	7.55	—	—	—
95	105	105	7.47	7.49	7.36	45.5	48.5	57.5
100.5	103	102	7.41	7.40	7.55	47.5	53	56
97	105	103	7.58	7.30	7.36	68	64	61
105	105	105	7.47	7.43	7.49	28	63	75
96.5	103	102	7.31	7.30	7.21	55	80	82
100	97.5	98	7.45	7.40	7.35	41	80	—

*O_2 saturation determinations performed on Cuvette oximeter, Waters Corp., Rochester, Minn.

The anatomic configuration of the left ventricle is such that the balloon, while obstructing the mitral valve, left the area of outflow tract at the aortic orifice and the membranous interventricular septum relatively free from impingement. This permitted direct inspection of the aortic valve apparatus through septal defects and reduced the risk of damaging the balloon when inserting sutures for repair of the defects. The presence of a small atrial septal defect does not greatly effect this method of bypass.

The effects of the differing peripheral resistances in the two circuits were investigated by comparing pulmonary and systemic pressures during several perfusions. With a balanced perfusion, pressures were dictated by the system's particular resistance. Thus, in one experiment, systemic arterial pressure was recorded at a mean of 120 mm. Hg with a femoral venous pressure of 10 cm. of saline. The simultaneous recordings in the left pulmonary artery and right upper pulmonary vein were 20 mm. Hg and 2 cm. of water, respectively.

Pathologic examination of survivors failed to show injury to the mitral valve apparatus or pulmonary tissue due to the balloon distention or system of cardiac bypass.

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*Sigmamotor Inc., Middleport, N. Y.

SUMMARY

Attempts at extending the efficiency and utilization of cardiac bypass circuits have generally been in the direction of mechanical improvements to existing systems with various modifications to pumps and artificial means of oxygenation. Failure to incorporate the pulmonary circulation has neglected the most efficient oxygenator available. The pulmonary vascular bed is also an excellent filtration system. Moreover, strong clinical evidence suggests that the exclusion of the pulmonary circulation from participating in a bypass circuit may contribute to postoperative respiratory complications.

Dispensing with an artificial oxygenator has several other practical advantages. We have reduced the quantity of priming blood to about 1 L. and the danger of transfusion reactions and various minor and major incompatibility problems are correspondingly lessened. This, together with the removal of the traumatic factors inherent in artificial oxygenation, has contributed to notable absence of postoperative bleeding.[9]

The most satisfactory results of incorporating the pulmonary circuit have been the high flow rates and physiologic blood pressures that were achieved without compromising blood gas exchange and without increasing the complexity of the circuit. We feel that this is most important, permitting a complete oxygenation of tissues and prolonging the permissible period a cardiac bypass. To test this observation, dogs were subjected to a 2 hour bypass with cardiac arrest. During this time normal blood pressure was maintained with constant reservoir levels. Blood chemistry was within normal limits and hemolysis 100 mg. per cent. At the conclusion of bypass, normal cardiac activity resumed. The net results of our technique have therefore been (1) a simplification of the extracorporeal handling of the blood and (2) a maintenance of physiologic homeostasis during the bypass. Andreason and Watson[10] and Cohen and Lillehei[11] have demonstrated that sub basal perfusion may be tolerated by the body for limited periods of approximately 30 minutes, but extension of this time is accompanied by a great increase in the operative mortality and morbidity. This is particularly applicable in pediatric practice. We believe that this method of extending the period of cardiac bypass will enable repair of the more complicated cardiac defects, particularly those in the tetralogy group. It will also, by reducing the operable age, increase our present salvage rate. In this younger group, in particular, the flow through abnormal bronchopulmonary anastomosis in a bypass procedure with artificial oxygenation may be intolerable in relation to total blood volume. In the closed circuits incorporating both systemic and pumonary systems which we have described, flow through these abnormal shunts is handled by the left atrial cannula. We do not feel that the application of this procedure will in any way be limited by the state of pulmonary vasculature or the respiratory capacity of the patient, provided other criteria of operability are applied.

Indeed a pressure recording in the pulmonary circuit before establishing total bypass may well indicate the state of pulmonary resistance present and the ultimate prognosis. When the vena caval to pulmonary artery circuit is established the effect of the defect on pulmonary artery pressure is eliminated (the pulmonary artery being temporarily clamped). In even the intensely cyanotic individual more than adequate oxygenating capacity is available once the abnormal vascular shunts and obstructions are bypassed at the cardiac level.

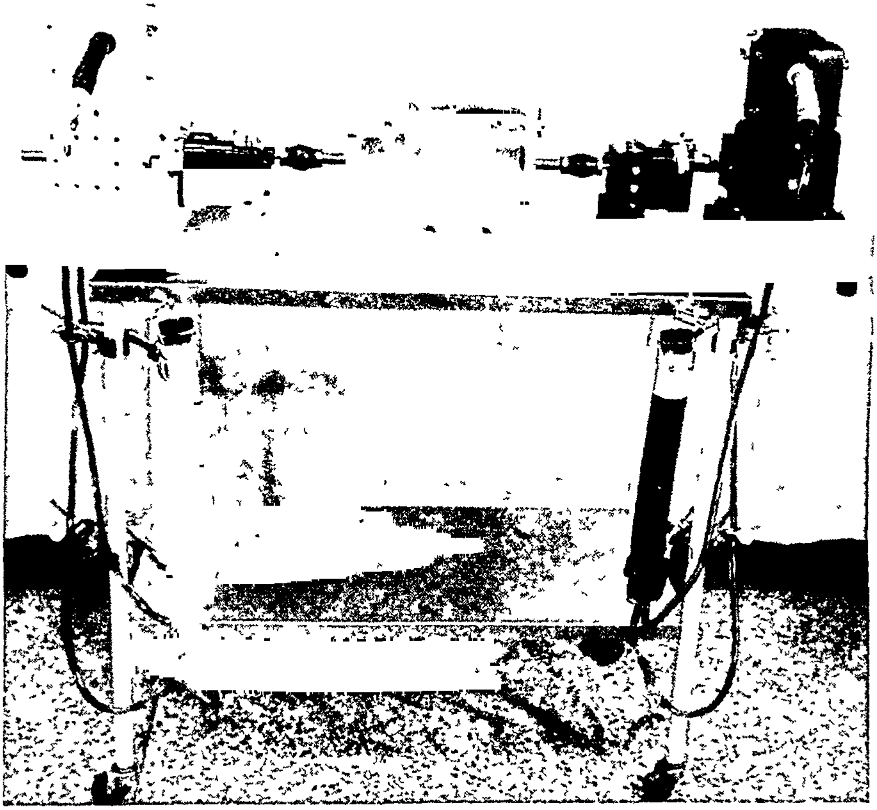

Fig. 2.—Photograph of extracorporeal circuit (reservoir water baths removed).

The two additional cannulations required in this bypass are technically easy and do not prolong operative time excessively or require additional exposure. Their incorporation has achieved the advantages mentioned above and the simplification of the extracorporeal circuit illustrated in the accompanying figure (Fig. 2).

CONCLUSIONS

1. A method of cardiac bypass using autogenous lung oxygenation is described.

2. Aerated lung fields are perfused with vena caval return. Oxygenated blood is cannulated from the left atrium for systemic perfusion. By occluding the mitral valve with a distensible balloon, a dry cardiotomy incision is obtained.

3. Results of animal experiments are given.

4 Advantages of this procedure over cardiac bypass techniques entailing artificial oxygenation are listed Notable among these are the high perfusion rates, reduced blood handling and trauma, and simplicity of the extracorporeal circuit

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(For Discussion see page 530)

MONITOR AND CONTROL OF BLOOD OXYGEN TENSION AND pH DURING TOTAL BODY PERFUSION

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During total body perfusion, the respiratory functions of the body are completely dependent upon the function of a mechanical device. In fact, all of the biochemical functions depend upon the performance of the perfusion apparatus since the vital metabolic organs must also be properly perfused to maintain their normal function.

All lung machines, like the human lung, can be over- or underventilated. Therefore, some control over carbon dioxide exchange is desirable. Similarly, all lung machines can provide too little or perhaps too much oxygen in arterial blood; for this reason, some control over oxygen tension is desirable. All heart machines, like the human heart, are capable of underperfusing and presumably overperfusing the body, so that some control of pumping rate or flow rate is desirable.

Control of the gaseous composition of *arterial* blood is largely a matter of control of gas flow rates in the machine. On the other hand, control of the gaseous composition of *venous* blood is largely dependent upon perfusion rate.

The purpose of this paper is to describe the methods developed as well as the results obtained in the continuous measurement of arterial oxygen tension and pH in 32 consecutive patients who underwent cardiopulmonary bypass for the treatment of a variety of congenital cardiac defects.† The patients were perfused in normothermia at flow rates calculated from a nomogram based upon oxygen requirement, hemoglobin, and body weight.[1] Twenty-seven patients have done well after surgery. Of the five deaths, two occurred

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Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

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†The detailed diagnoses are as follows: 9, ostium secundum; 1, ostium secundum with anomalous pulmonary veins; 1, ostium primum; 12, isolated ventricular septal defects; 5, VSD with pulmonary stenosis (tetralogy of Fallot); and 4, isolated pulmonary stenosis (infundibular and/or valvular). The time of total perfusion varied between 15 and 69 minutes, with an average of 33 minutes.

4 and 6 weeks after surgery, two occurred within 48 hours after perfusion and were attributed to inoperable ventricular septal defects and one within 24 hours after perfusion due to an error in the maintenance of blood volume.

The interrelationships among pH, oxygen, and carbon dioxide tensions make it impossible to make separate statements about each but for the present purpose they will be discussed independently.

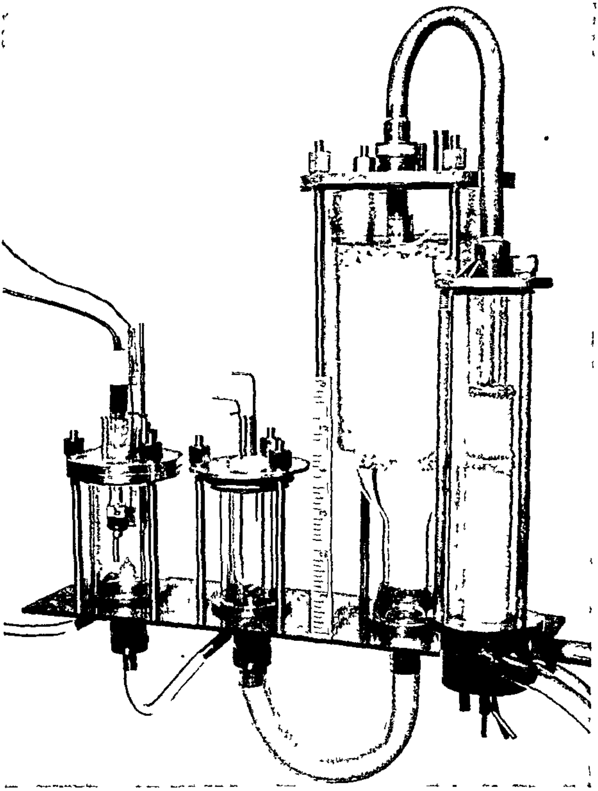

Fig. 1. Photograph of apparatus designed for perfusion of infants, where a low blood volume, high output machine is required. This apparatus has a priming volume of 450 c.c. and an output of over 1,200 c.c. per minute.

METHOD

The perfusion machine used is based upon the bubble-defoam principle.[2] The apparatus (Fig. 1) consists of a bubbling unit equipped with sintered glass cylinders of two porosities such that flow of fine (10 to 50 micron) and coarse (1 to 3 mm.) bubbles can be independently regulated (Fig. 2). Defoaming takes place on polymethylsiloxane-coated Teflon ribbons held in a Pyrex chamber. Pumping is accomplished with high precision, using an electronically controlled oxygen piston.[3] Electrodes for measuring pO_2, pH, and temperature are suspended in a chamber (Fig. 3) mounted in the arterial stream. With the exception of the pH electrodes the entire unit is autoclaved.

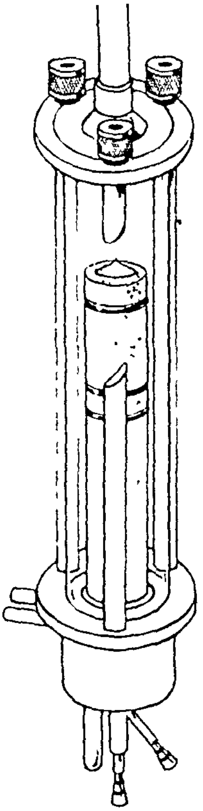

Fig. 2.

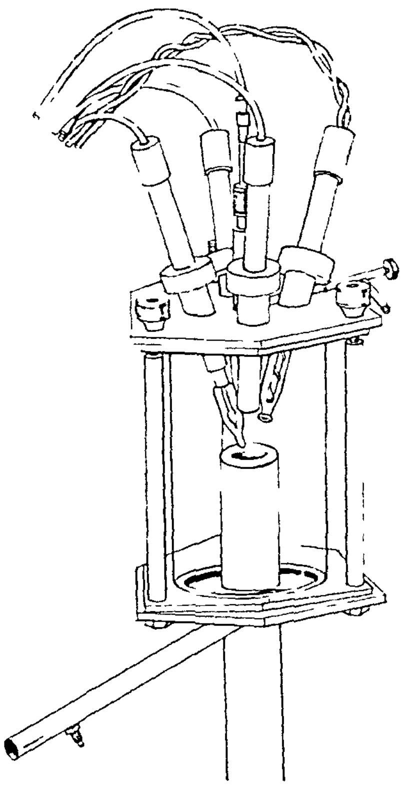

Fig. 3.

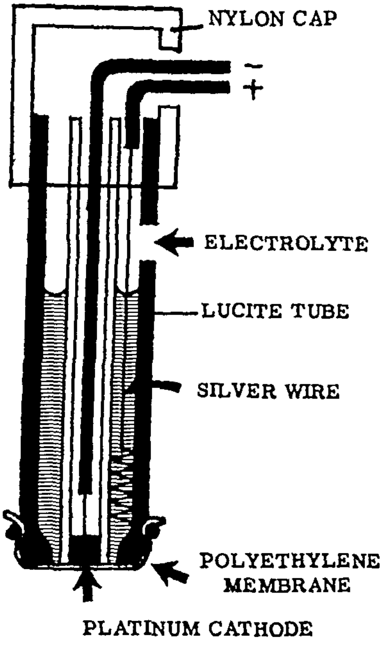

Fig. 4.

Fig. 2.—Bubbler unit. Bubbling is accomplished by forcing oxygen through a 1-inch long section of Pyrex sintered-glass cylinder (coarse) and a 1-inch long Pyrex sintered fine-porosity cylinder. Both have diameters of 1 inch. Blood circulates around the outside of the porous tubes held in the vertical glass cylinder. Oxygen is passed to each porous tube by the separate inlets shown at the bottom of the unit. Venous blood enters the two tubulations shown on the lower left. Disposable porous bubbler units have been developed and are available from the Selas Corp., Philadelphia, Pa.

Fig. 3.—Monitor chamber. In routine use this chamber contains a glass pH electrode, a reference pH electrode, a thermistor thermometer probe, and a Clark oxygen electrode.

Fig. 4.—Diagram of Clark oxygen electrode. The glass-insulated platinum cathode presses against a 1 mil (0.001 inch) polyethylene membrane. The outer tube is made of Lucite and holds saturated KCl which forms an extremely thin (capillarity) layer between the platinum and the polyethylene. The lead wires are sealed in a nylon cap filled with cast acrylic. The anode (reference electrode) is a silver wire immersed in the electrolyte.

Oxygen tension was measured with the membrane electrode described by Clark and associates[4, 5] and shown in Fig. 4. Most of the determinations were conducted using a polyethylene membrane, although recently Teflon membrane has been used in an autoclavable electrode. Application of the electrode in blood oxygen analysis has been reported by others[6-8] while Sawyer and George[10] have studied its application to other gases. The circuitry and recording apparatus has been previously described.[11]*

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*A simple polarograph circuit is available from the authors.

The pH was monitored either with a conventional glass electrode together with a calomel reference electrode or with a "combination" glass-AgCl-Ag electrode. An industrial pH meter was used in connection with a Brown recorder for recording the arterial pH.* The glass electrode was coated with silicone. Provision was made to keep the pressure of the saturated electrolyte *in the reference electrode above that of the blood.*

Blood temperature was automatically controlled at 37.5° ± 0.5° C. and subsequently monitored by a thermistor-type thermometer.[12] Venous blood samples were taken from the venous inflow to the machine and analyzed by Van Slyke methods.

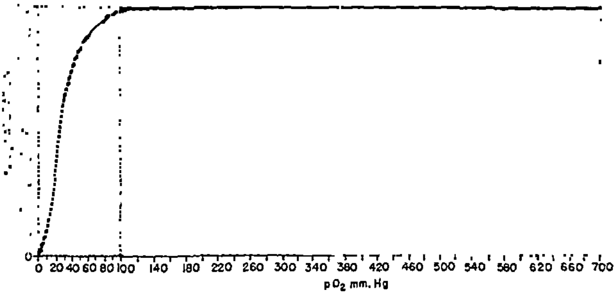

Fig. 5.—Oxygen saturation versus oxygen tension. This is a diagrammatic representation to illustrate the large range of oxygen pressures (from 100 to 700) which do not lend themselves to analysis by conventional Van Slyke or spectrophotometric procedures

RESULTS

Blood-Oxygen Tension.—During perfusion, the arterial oxygen tension in all patients was maintained between 400 and 600 mm. Hg. This range of tension was selected for several reasons. It was considered sufficiently below complete saturation of the plasma with oxygen to obviate the possibility of oxygen embolism; furthermore, animal experiments showed it to be completely safe for periods of total perfusion of at least 1 hour. By nearly saturating the plasma with oxygen it is possible to increase the oxygen transport capacity of the blood by an amount roughly equivalent to that of an extra gram of hemoglobin per 100 c.c. Last, it is easy to operate the machine in this range of arterial oxygen tension for it tends to be automatically held there, by virtue of the reduced pressure (–100 mm. Hg) in the defoaming chamber and to give ample time for warning (Figs. 5 and 7) of the need for addition of more oxygen *(fine bubbles) in the event that the tension begins to decrease. This method* of monitoring has proved to be reliable. Monitoring of venous oxygen tension has been equally reliable but less valuable because of the small changes in tension which accompany large changes in venous oxygen capacity or flow rate.[1]

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*The equipment used for pH is the Model W industrial pH meter (Beckman Instrument, Inc., Fullerton, Calif.) equipped with fixed resistor instead of temperature compensating electrode and with resistor to give 10 mv. output in range of pH 6 to 8; a Minneapolis-Honeywell recorder having exact range –5 mv. to +5 mv. with center 0 and chart speed of an inch per 7½ minutes or an inch per minute. Special pH recording-paper scale (6 to 8) is available as Plate 731.

TABLE I. ARTERIAL BLOOD pH

PATIENT NUMBER	MINUTES															MEAN
	-5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	
2	7.55	7.50	7.44	7.42	7.41	7.42	7.43	7.42								7.42
3	7.43	7.42	7.40	7.40	7.40	7.40	7.40	7.39	7.39	7.40	7.40	7.40	7.40			7.40
4	7.42	7.41	7.45	7.43	7.42	7.40	7.39	7.37	7.40	7.41	7.37	7.39				7.40
5	7.60	7.64	7.61	7.63	7.60	7.55	7.53	7.49	7.48	7.47	7.46	7.47	7.48			7.52
6	7.35	7.35	7.40	7.40	7.44	7.43	7.45	7.46								7.43
7	7.44	7.43	7.44	7.40	7.44	7.45	7.43	7.39	7.40	7.43	7.44	7.45				7.43
8	7.62	7.67	7.56	7.50	7.42	7.48										7.49
9	7.75	7.65	7.53	7.60	7.50	7.48	7.47	7.50								7.51
10	7.45	7.42	7.36	7.37	7.37	7.35	7.35	7.36								7.36
11	7.42	7.44	7.42	7.41	7.40	7.41	7.41	7.43	7.42	7.43	7.42	7.42	7.42			7.42
12	7.44	7.43	7.43	7.45	7.43	7.44										7.44
13	7.48	7.48	7.43	7.45	7.44											7.44
14	7.38	7.43	7.42	7.43	7.43	7.43										7.43
15	7.42	7.38	7.37	7.37	7.36	7.35	7.36									7.36
16	7.43	7.41	7.42	7.39	7.43	7.43	7.44									7.42
17	7.47	7.47	7.45	7.41	7.44	7.43	7.43	7.44	7.47	7.46	7.42	7.42	7.41	7.41		7.43
18	7.40	7.37	7.36	7.38	7.39	7.39	7.40	7.39								7.39
19		7.35	7.36	7.35	7.38	7.40	7.43	7.44								7.39
20	7.45	7.47	7.42	7.41	7.40	7.40	7.44									7.41
21	7.42	7.44	7.41	7.42	7.42	7.42	7.42									7.42
22	7.44	7.43	7.38	7.38	7.38	7.38	7.38	7.38	7.39	7.41						7.39
23	7.42	7.43	7.43	7.41	7.43	7.44	7.42									7.43
24	7.44	7.43	7.42	7.41	7.42	7.42	7.42	7.43								7.42
26	7.37	7.39	7.37	7.36	7.40	7.42	7.43	7.43								7.40
27	7.51	7.51	7.43	7.45	7.40	7.43	7.42	7.43	7.45	7.40	7.41	7.43	7.44	7.43	7.43	7.43
28	7.47	7.43	7.42	7.41	7.42	7.42	7.43	7.43								7.42
29	7.43	7.43	7.34	7.39	7.38	7.40										7.38
30	7.40	7.42	7.42	7.42	7.43	7.42	7.42									7.42
31	7.36	7.38	7.41	7.40	7.39	7.38	7.38	7.40								7.39
32	7.50	7.49	7.43	7.43	7.43	7.43	7.44	7.44	7.44							7.44
Mean S.D.	7.46 ±.08	7.45 ±.08	7.42 ±.06	7.42 ±.06	7.42 ±.04	7.42 ±.04	7.42 ±.04	7.42 ±.04	7.43 ±.03	7.43 ±.03	7.42 ±.03	7.43 ±.03	7.43	7.42	7.43	7.42 ±.04

Venous saturations were between 56.8 and 83.4 per cent in the 22 patients studied, with the mean at 72.5 per cent. Individual patients maintained a remarkably constant venous saturation.

Hydrogen Ion Concentration.—The continuous records obtained by monitoring arterial blood pH were measured and tabulated as shown in Table I. The mean pH for 30 patients was 7.42, with a standard deviation of ± 0.04. There is a tendency for the blood pH to be somewhat high during the first 5 minutes preceding and the first 5 minutes succeeding the beginning of total body perfusion. This appears to be due to the slightly above normal pH of the (recirculated) donor blood, and use of a somewhat excessive amount of large bubbles as the machine is started. *After perfusion is under way, the pH can be controlled with remarkable precision, as indicated by the data displayed in the table.*

TABLE II. VENOUS BLOOD CARBON DIOXIDE

PATIENT NUMBER	VOLUMES PER CENT				
	0-10 MIN.	11-20 MIN.	21-30 MIN.	31-60 MIN.	MEAN
11	35.8	35.1		33.6, 34.7	34.8
12	41.2, 41.6	40.1			41.1
13	50.2	48.2			49.2
14	41.4	42.1, 39.3			40.9
15	39.5	37.2, 38.6			38.4
16		39.3	43.8		41.6
17		55.5, 52.6	52.4		53.5
18	44.4	43.0	40.8		42.7
19	48.9	44.2	41.1, 42.0		44.7
20	44.5	44.1, 41.7			43.4
21	45.1	41.8	42.2		43 0
22	39.2, 39.4		39.4	37.2	38.8
23	38.9, 41.7	39.9			40.2
24	42.4	42.4, 42.4	42.1		42.3
25		41.0, 40.8	40.9		40.9
26	38.4	39.3, 38.3	39.3		39.0
27		44.1	42.7	45.5, 42.8	43.8
28	38.3	41.2	39.6	38.9	39.5
29	44.9	39.8			42.4
30	41.8	40.3			41.1
31		39.9, 36.6			38.3
32	37.9	39.2	38.2		38.4
Mean	41.8	41.7	41.9	38.8	41.7
Range	(35.8-50.2)	(35.1-55.5)	(38.2-52.4)	(33.6-45.5)	(34.8-53.5)
S.D.	±3.6	±4.2	±3.4	±4.2	±3.8
Expressed as mM per liter:					
Mean	18.8	18.7	18.8	17.4	18.7
Range	(16.1-22.5)	(15.8-24.9)	(17.2 23.5)	(15.1-20.4)	(15.7-24.0)
S.D.	±1.6	±1.9	±1.5	±1.9	±1.7

Technical difficulty with pH monitoring was encountered in 3 patients of the 32 perfused; this was due to blood entering the reference electrode.

While control of blood pH is, of course, important in itself, the main purpose of the pH monitoring was to have an index of arterial pCO_2. The effectiveness of this indirect control is discussed below.

Venous Blood Carbon Dioxide.—The data obtained by analysis of venous blood for carbon dioxide are shown in Table II. The mean veno [illegible] blood

TABLE I. ARTERIAL BLOOD pH

PATIENT NUMBER	MINUTES															MEAN
	–5	0	5	10	15	20	25	30	35	40	45	50	55	60	65	
2	7.55	7.50	7.44	7.42	7.41	7.42	7.43	7.42								7.42
3	7.43	7.42	7.40	7.40	7.40	7.40	7.40	7.39	7.39	7.40	7.40	7.40	7.40			7.40
4	7.42	7.41	7.45	7.43	7.42	7.40	7.39	7.37	7.40	7.41	7.37	7.39				7.40
5	7.60	7.64	7.61	7.63	7.60	7.55	7.53	7.49	7.48	7.47	7.46	7.47	7.48			7.52
6	7.35	7.35	7.40	7.40	7.44	7.43	7.45	7.46								7.43
7	7.44	7.43	7.44	7.40	7.44	7.45	7.43	7.39	7.40	7.43	7.44	7.45				7.43
8	7.62	7.67	7.56	7.50	7.42	7.48										7.49
9	7.75	7.65	7.53	7.60	7.50	7.48	7.47	7.50								7.51
10	7.45	7.42	7.36	7.37	7.37	7.35	7.35	7.36								7.36
11	7.42	7.44	7.42	7.41	7.40	7.41	7.41	7.43	7.42	7.43	7.42	7.42	7.42			7.42
12	7.44	7.43	7.43	7.45	7.43	7.44										7.44
13	7.48	7.48	7.43	7.45	7.44											7.44
14	7.38	7.43	7.42	7.43	7.43	7.43										7.43
15	7.42	7.38	7.37	7.37	7.36	7.35	7.36									7.36
16	7.43	7.41	7.42	7.39	7.43	7.43	7.44									7.42
17	7.47	7.47	7.45	7.41	7.44	7.43	7.43	7.44	7.47	7.46	7.42	7.42	7.41	7.41		7.43
18	7.40	7.37	7.36	7.38	7.39	7.39	7.40	7.39								7.39
19		7.35	7.36	7.35	7.38	7.40	7.43	7.44								7.39
20	7.45	7.47	7.42	7.41	7.40	7.40	7.44									7.41
21	7.42	7.44	7.41	7.42	7.42	7.42	7.42									7.42
22	7.44	7.43	7.38	7.38	7.38	7.38	7.38	7.38	7.39	7.41						7.39
23	7.42	7.43	7.43	7.41	7.43	7.44	7.42									7.43
24	7.44	7.43	7.42	7.41	7.42	7.42	7.42	7.43								7.42
26	7.37	7.39	7.37	7.36	7.40	7.42	7.43	7.43								7.40
27	7.51	7.51	7.43	7.45	7.40	7.43	7.42	7.43	7.45	7.40	7.41	7.43	7.44	7.43	7.43	7.43
28	7.47	7.43	7.42	7.41	7.42	7.42	7.43	7.43								7.42
29	7.43	7.43	7.34	7.39	7.38	7.40										7.38
30	7.40	7.42	7.42	7.42	7.43	7.42	7.42									7.42
31	7.36	7.38	7.41	7.40	7.39	7.38	7.38	7.40								7.39
32	7.50	7.49	7.43	7.43	7.43	7.43	7.44	7.44	7.44							7.44
Mean S.D.	7.46 ±.08	7.45 ±.08	7.42 ±.06	7.42 ±.06	7.42 ±.04	7.42 ±.04	7.42 ±.04	7.42 ±.04	7.43 ±.03	7.43 ±.03	7.42 ±.03	7.43 ±.03	7.43	7.42	7.43	7.42 ±.04

Venous saturations were between 56.8 and 83.4 per cent in the 22 patients studied, with the mean at 72.5 per cent. Individual patients maintained a remarkably constant venous saturation.

Hydrogen Ion Concentration.—The continuous records obtained by monitoring arterial blood pH were measured and tabulated as shown in Table I. The mean pH for 30 patients was 7.42, with a standard deviation of ± 0.04. There is a tendency for the blood pH to be somewhat high during the first 5 minutes preceding and the first 5 minutes succeeding the beginning of total body perfusion. This appears to be due to the slightly above normal pH of the (recirculated) donor blood, and use of a somewhat excessive amount of large bubbles as the machine is started. After perfusion is under way, the pH can be controlled with remarkable precision, as indicated by the data displayed in the table.

TABLE II. VENOUS BLOOD CARBON DIOXIDE

PATIENT NUMBER	VOLUMES PER CENT				
	0 10 MIN.	11-20 MIN.	21-30 MIN.	31-60 MIN.	MEAN
11	35.8	35.1		33.6, 34.7	*34.8*
12	41.2, 41.6	40.1			*41.1*
13	50.2	48.2			*49.2*
14	41.4	42.1, 39.3			*40.9*
15	39.5	37.2, 38.6			*38.4*
16		*39.3*	*43.8*		*41.6*
17		55.5, 52.6	52.4		*53.5*
18	44.4	43.0	40.8		*42.7*
19	48.9	44.2	41.1, 42.0		*44.7*
20	44.5	44.1, 41.7			*43.4*
21	45.1	41.8	*42.2*		*43.0*
22	39.2, 39.4		*39.4*	*37.2*	*38.8*
23	38.9, 41.7	39.9			*40.2*
24	42.4	42.4, 42.4	42.1		*42.3*
25		41.0, 40.8	40.9		*40.9*
26	38.4	39.3, 38.3	39.3		*39.0*
27		44.1	*42.7*	*45.5, 42.8*	*43.8*
28	38.3	41.2	39.6	*38.9*	*39.5*
29	44.9	39.8			*42.4*
30	41.8	40.3			*41.1*
31		39.9, 36.6			*38.3*
32	37.9	39.2	38.2		*38.4*
Mean Range S.D.	41.8 (35.8-50.2) ±3.6	41.7 (35.1 55.5) ±4.2	41.9 (38.2-52.4) ±3.4	*38.8* *(33 6 45 5)* *±4.2*	*41.7* [illegible] [illegible]
Expressed as mM per liter:					
Mean Range S.D.	18.8 (16.1 22.5) ±1.6	18.7 (15.8-24.9) ±1.9	*18.8* *(17.2-23.5)* *±1.5*	*17.4* *(15 1-20 4)* *±1.9*	[illegible]

Technical difficulty with pH monitoring was *encountered in* [illegible] the 32 perfused; this was due to blood entering *the* [illegible]

While control of blood pH is, of course, *important in the* [illegible] pose of the pH monitoring was *to have an index of* [illegible] tiveness of this indirect control is *discussed below.*

Venous Blood Carbon Dioxide.—The data [illegible] blood for carbon dioxide *are shown in Table II.* [illegible]

CO_2 content was 41.7 volumes per cent (18.7 mM per liter) which gives a mean calculated pCO_2 of approximately 33 mm. Hg. These figures are within the range of normal.

The venous carbon dioxide can be held constant over a period of perfusion, as indicated by average values given at the bottom of the table. However, the carbon dioxide content of the blood of *individual* patients varied from 34.8 to 53.5 showing, as might be expected, that at a constant regulated pH, the venous CO_2 content varied considerably, although within a tolerable range.

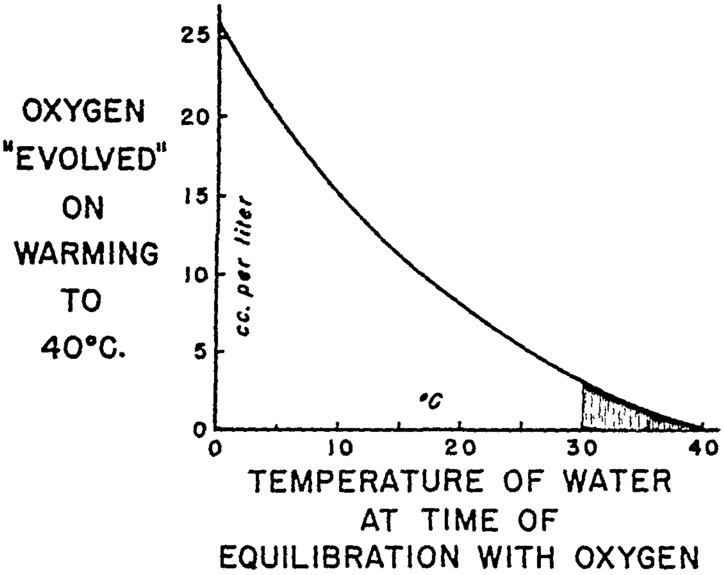

Fig. 6.—Temperature-solubility relationship. Data obtained from Handbook of Physics and Chemistry, Cleveland, Ohio, 1957, Chemical Rubber Publishing Co.

Because small changes in blood pCO_2 have a greater physiologic effect than small changes in blood pH, particularly on cerebral circulation, it may be desirable in the future to continuously monitor pCO_2 directly by an electrochemical method, such as that of Stow and associates.[13] Simultaneous continuous measurement of pCO_2 and pH would provide a very sensitive index of the onset and course of metabolic acidosis. In certain types of blood-gas exchange units it should be equally valid, and perhaps simpler, to monitor the CO_2 content of the effluent gas from the machine.

Intravenous alkali therapy was not used during perfusion or afterward.[11]

Temperature.—Our perfusions in man have been conducted with blood automatically regulated to 37.5° C. Use of blood at constant temperature has, aside from the "physiological" arguments, the advantage of eliminating temperature corrections on the measuring electrodes, thus making the instruments direct-reading. The pH and pO_2 electrodes are standardized at 37.5° C. before the perfusion begins and checked again after the perfusion is completed. (pH electrodes, which have been silicone-coated by exposure to silicone oxychloride vapors, maintain their standardization to within ± 0.02 after prolonged exposure to blood.)

Gas solubility is perhaps the main practical consideration as far as temperature effects in blood are concerned. We have been unable to find studies of this factor for whole blood, but Fig. 6 illustrates the magnitude of the temperature-solubility effect for oxygen-saturated water. During rapid cooling and rewarming, the large temperature differences found in different organs suggest that differential organ oxygen embolism could be produced.

Simultaneous Recording.—Fig. 7 is given to summarize many of the concepts described. It shows actual records of pO_2, pH, and arterial blood pressure during total perfusion of a dog at a rate of 1.2 L. per minute. There is a 600 c.c. blood volume in the apparatus between the point of entry of the oxygen and the monitor chamber and thus, at this flow rate, a 30-second lag between changes in oxygen gas flows and the recording of the effect.

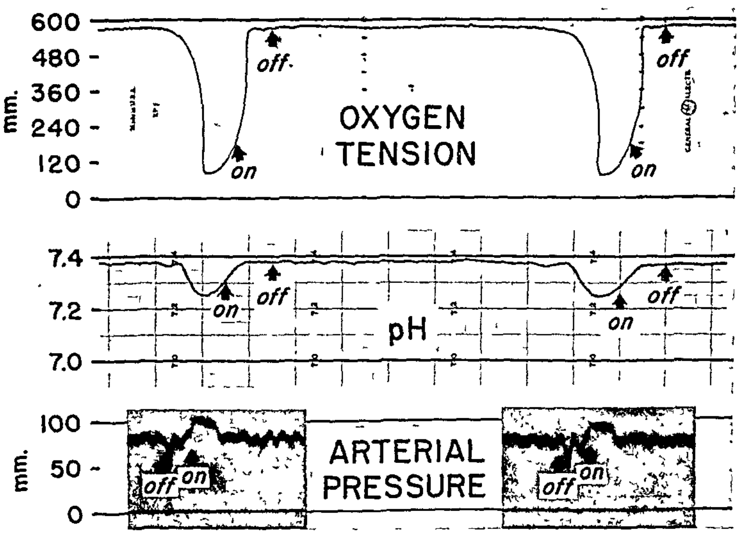

Fig 7—Simultaneous recordings of blood oxygen tension, blood pH, and arterial pressure. The pO_2 and pH records read from right to left. *Off* indicates clamping the oxygen supply to the bubbling unit, *on* indicates return of the oxygen bubbles. The curved vertical lines in the background of the pO_2 record indicate 30-second intervals.

In this experiment, the total supply of oxygen to the bubbler was clamped for exactly 1 minute. The oxygen tension fell from about 580 mm. to 75 mm., the pH fell from 7.37 to 7.25, the blood pressure rose from 80 to 100, with a prompt return to original values. The precision with which the effect could be duplicated is also shown. It can be demonstrated that by clamping the large bubble supply, a pH drop occurs, while the arterial pO_2 remains above 500 mm. Similarly, by clamping the fine bubble supply, the arterial tension can be dropped several hundred millimeters while maintaining the blood pH without change.

In the experiment shown in Fig. 7, the return to normal values was rapid and complete; however, if the period of h[illegible] w[illegible] [illegible]ded [illegible] [illegible]ond this time, changes in blood pH were produced which could only be reversed by intravenous alkali.

SUMMARY

Methods for the continuous measurement and recording of oxygen tension and hydrogen ion concentration have been developed and applied to the control of total body perfusion in man. Their application has made it possible accurately to control arterial oxygen tension and, through pH, to gain adequate control of carbon dioxide tension.

We gratefully acknowledge the assistance of Mrs. S. Kaplan, Miss Ruth Parker, Mrs. Stephanie Reichman, and Miss R. Phyllis Fox.

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(For Discussion, see page 530)

EXPERIMENTAL AND CLINICAL STUDIES OF CONTROLLED HYPOTHERMIA RAPIDLY PRODUCED AND CORRECTED BY A BLOOD HEAT EXCHANGER DURING EXTRACORPOREAL CIRCULATION

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In previous reports,[1, 2, 3] we have described our experience employing a combination of hypothermia and extracorporeal circulation for open heart surgery. In our first 50 cases using this combination, we used the usual methods of achieving hypothermia such as ice packs, refrigerated blankets, etc. However the well known disadvantages of these methods, such as the time required for cooling and rewarming, lengthening of anesthesia time, poor control and downward drift of temperature, prompted us to evaluate the method of direct blood cooling as described in animals by Gollan[4, 5] and Pierce[6] and their associates and in a limited number of patients by Ross.[7] During this past year we described a simple blood heat exchanger for use with extracorporeal circulation[8, 9] and later reported our initial experiences employing it for clinical open heart surgery.[10]

Briefly, the heat exchanger assembly consists of an automatic thermostatic water mixing valve, heat exchange unit and bubble trap filter unit all mounted on a pole type floor stand. The automatic thermostatic water mixing valve blends hot and cold tap water carried to it by ordinary garden hoses. The water entering the heat exchange unit is automatically and precisely thermoregulated regardless of fluctuations in supply water temperature or pressure and flows through the exchanger at a rate of three gallons per minute. The design and construction of the all stainless steel exchanger unit[9] were based specifically upon the physical properties and exacting requirements of human blood. The exchanger, although it has a blood volume of only 175 c.c., nevertheless has a very high efficiency of heat transfer as illustrated in Fig. 1. After flowing through the exchanger unit, the blood passes into an efficient bubble trap filter and thence into the patient's artery. An autoclavable thermistor probe in the

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bottom of the bubble trap continuously monitors the inflow blood temperature. The heat exchanger assembly may be used with any type of extracorporeal circuit and is interposed in the inflow line between the heart-lung machine and patient's cannulated artery.

In evaluating this method of producing hypothermia clinically, a number of questions have arisen. First, what relative velocities of cooling and rewarming could be achieved by it? Second, does this method of rapidly producing hypothermia cool all the vital organs sufficiently? Does the high oxygen saturation of the mixed venous blood that occurs with this internal cooling truly reflect cooling and therefore less oxygen consumption by all the vital organs or does the venous oxygen saturation from some of these organs fall to undesirable levels while the mixed venous oxygen saturation is maintained? It was also desirable to know whether or not the site of entry into the body of the exchanger-cooled blood was of major importance. For the control of the hypothermia, it was important to determine what accessible location in the body most closely reflected vital organ temperature. The answers to these problems were sought through the following experimental and clinical studies.

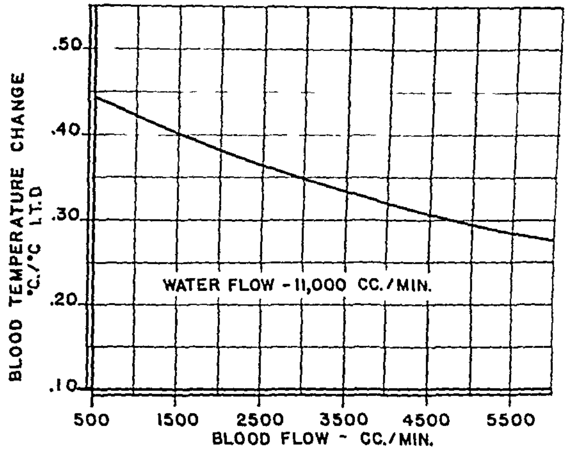

Fig. 1.—Graph showing blood temperature change across the heat exchanger per degree centigrade of the temperature difference between inlet blood and inlet water. If the inlet temperatures of the blood and water are known, then the temperature change that would take place in the blood between the exchanger inlet and outlet can be determined by multiplying the factor obtained on the ordinate from the curve and blood flow rate by the blood-water inlet temperature difference (I. T. D.).

METHODS

Healthy mongrel dogs varying in weight from 11 to 24 Kg. were anesthetized with intravenous sodium pentobarbital, intubated, and mechanically respirated with room air. In certain experiments, thermistor needles or probes were inserted into the cerebral cortex, right heart, midesophagus, liver, kidney cortex, rectum, and thigh musculature and connected to calibrated telethermometers. Cardiopulmonary bypass was then carried out using a slightly modified DeWall type bubble oxygenator and Sigmamotor pump, the vascular connections being made with the femoral (or left subclavian) artery and superior and inferior venae cavae by way of the external jugular vein, right auricle, or femoral vein. Temperature records of velocities of cooling and rewarming were then determined with the heat exchanger for various perfusion rates and water-blood thermal gradients.

In other dog experiments, in addition to the above preparations, small polyethylene catheters were inserted in the sagittal venous sinus, right auricle, hepatic vein, renal vein, superficial femoral vein, and occasionally a mesenteric vein in order to obtain anaerobically samples of venous blood from these organs for oxygen analysis.

Additional samples were taken anaerobically of arterial blood and of the mixed venous blood from the venous return to the heart-lung machine. The blood samples were taken after 15 to 30 minutes of perfusion at different flow rates with varying degrees of hypothermia. Oxygen saturation was determined by the method of Hickam and Frayser.[10] Hemoglobin concentration was determined by the cyanmethemoglobin method of Drabkin.[11] Due to the nature of these experiments involving extensive dissection, craniotomy, and thermistor probe injury to the cerebral cortex, etc., no attempt for survival was made and all the animals were sacrificed at the end of the experiments.

In our clinical studies made during open heart operations combining hypothermia and extracorporeal circulation, thermistor probes have been inserted in the high rectum and mid esophagus. In many patients deep thigh and back musculature temperatures have been recorded from needle thermistors. In a few patients, the cerebral venous blood temperature has been recorded from a small catheter thermistor probe inserted into the right jugular bulb at the base of the brain via the right auricle and internal jugular vein. Arterial and mixed venous blood samples have been taken from many of these patients at intervals during and after operation for oxygen saturation, CO$_2$ content, and pH determinations.

RESULTS AND DISCUSSION

Rates of Cooling and Rewarming.—Studies of body cooling and rewarming velocities employing the heat exchanger have shown some variations in both dog and man. However, with moderate blood flow rates of 35 to 50 c.c./Kg./min. (0.9 – 1.3 L./M.²/min.) it has been possible to reduce the mid esophageal temperature from 37° to 30°-31° C. in 5 to 7 minutes (Fig. 2). It was found that these velocities depend on many factors, including the cooling water temperature, size of patient, and perfusion rate; thus, cooling rates slower or faster than this may be obtained. For example, in 1 dog while employing a flow rate of 100 c.c./Kg./min. (2.25 L./M.²/min.) with an inflow blood temperature of 19° C., the temperature fell 7° C. in 1 minute.

Rewarming velocities have been slightly slower due to the thermal limits, still poorly defined, to which blood may be heated without damage. During rewarming, even though a wide blood-water thermal gradient may exist, the blood film contacting the walls of the heat exchanger may closely approach the temperature of the heating water. However, because of the exchanger's high heat transfer efficiency we have been able to rewarm dogs and patients at a bottom of the bubble trap continuously monitors the inflow blood temperature. The heat exchanger assembly may be used with any type of extracorporeal circuit and is interposed in the inflow line between the heart-lung machine and patient's cannulated artery.

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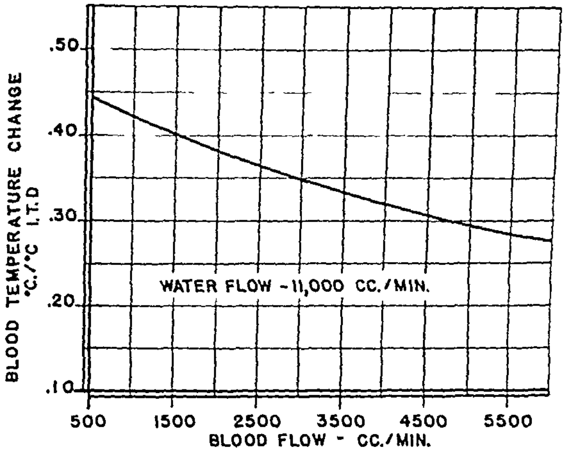

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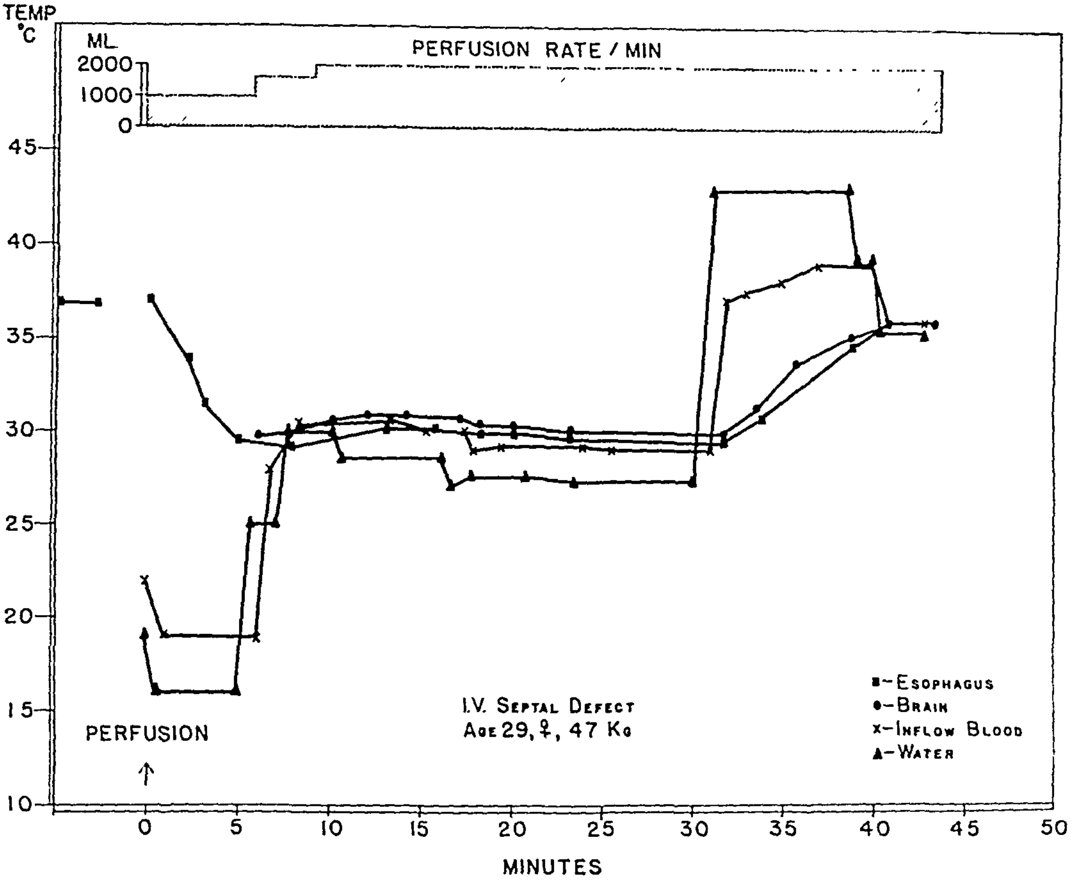

Fig. 2.—Graph of temperatures recorded during bypass interval in operation for interventricular septal defect. Note the rapid cooling velocity and plateau of esophageal and brain temperatures. The esophageal temperature is seen to return rapidly toward normal with the brain temperature immediately after the blood temperature was raised by the heat exchanger.

The heart, liver, and kidney in both the dog and man were found to cool the most rapidly, the brain and esophagus cooling only slightly slower. We have found this order of vital organ cooling rate to be essentially the same regardless of the site of arterial inflow. Rectal temperature has proved far less useful as a guide to vital organ temperature, showing considerable variation of response from patient to patient.

Studies of Fractional Venous Oxygen Saturation.—Data from 15 acute hypothermia perfusion experiments in dogs, during which oxygen saturations were determined on serial samples of venous blood from the brain, right heart, liver, kidneys and leg, are given in Table I. These data show, as would be expected, the highest mixed venous oxygen saturation in euthermic animals at the higher flow rates At flow rates below 75 c c /Kg /min (1 58 L /M^2/min) at 37° C , the mixed venous oxygen saturation falls below normal values with an average of 38 per cent saturation at flow rates of 25 c c /Kg /min (0 57 L /M^2/min) At 30° C , there is considerable improvement of mixed venous oxygen saturation in animals perfused at flow rates below 75 c c /Kg /min (1 58 L /M^2/min) and there is marked improvement at 25° C The data on oxygen saturation of venous blood from various organs also show these same trends with regard to flow rate and temperature

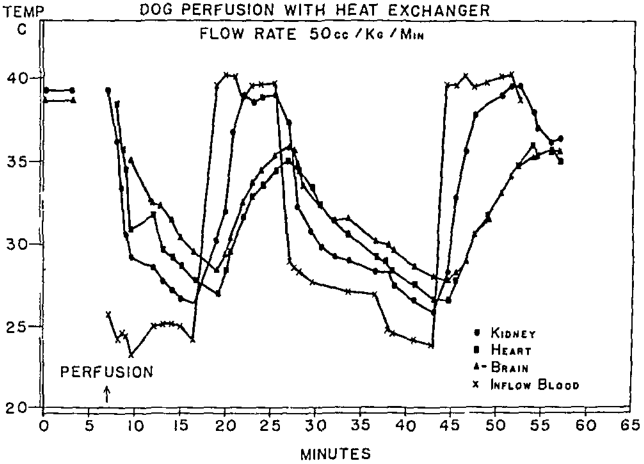

Fig 3 —Temperature chart from a typical dog cooling and rewarming experiment Note how closely the heart and kidney cooling and rewarming curves follow one another Note slightly slower response of the brain

In some experiments, while inserting the hepatic vein catheter, it was difficult to avoid contraction of the large hepatic vein sphincters,[12, 13, 14] that so frequently cause venous engorgement of the liver and obstruction to portal blood flow in experiments of this sort Thus, this physiologic mechanism, peculiar to the dog and certain other mammals, which caused hepatic congestion in some of the animals undoubtedly accounted for at least some of the low oxygen values obtained with the hepatic vein blood In addition, a few of the hypothermic animals developed moderate bradycardia with slower emptying of the right heart This may have lowered some of the oxygen values obtained with the right heart blood In general, however, these fractional venous oxygen values show good relative correlation with the mixed venous oxygen saturation data at the various flow rates and temperatures employed This would indicate that the level of mixed venous oxygen saturation reflects fairly accurately the relative oxygen saturation of the venous blood, at least from the organs studied

Table I

BLOOD SAMPLE SITE	FLOW RATE 100 C.C./KG., 2.15 L./M.² (AVG.)				FLOW RATE 75 C.C./KG., 1.58 L./M.² (AVG.)				FLOW RATE 50 C.C./KG., 1.19 L./M.² (AVG.)					
	ESOPHAGEAL TEMPERATURE				ESOPHAGEAL TEMPERATURE				ESOPHAGEAL TEMPERATURE					
	38° C.		30° C.		37° C.		30° C.		37° C.		30° C.		25° C.	
	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.
Artery*	38.0	100	28.5	100	36.8	100	29.5	100	37.5	100	29.9	100	25.0	100
Mixed venous	-	75	-	84	-	74	-	79	-	53	-	78	-	87
Brain	36.9	80	30.0	84	36.7	65	29.8	66	36.7	52	30.8	79	25.8	86
Rt. auricle†	37.5	42	29.8	68	36.8	46	29.0	-	35.9	50	29.8	71	25.2	65
Liver	37.4	39	29.9	66	37.2	45	29.5	57	36.5	48	29.2	73	25.8	94
Kidney	38.0	76	30.8	86	37.3	82	29.5	80	36.3	84	29.8	81	25.3	93
Leg	33.9	46	32.8	82	35.0	55	30.4	55	36.3	53	30.8	64	23.9	96
Rectum	37.1	-	30.2	-	36.9	-	30.9	-	36.6	-	29.2	-	25.5	-

BLOOD SAMPLE SITE	FLOW RATE 35 C.C./KG., 0.77 L./M.² (AVG.)						FLOW RATE 25 C.C./KG., 0.57 L./M.² (AVG.)					
	ESOPHAGEAL TEMPERATURE						ESOPHAGEAL TEMPERATURE					
	37° C.		30° C.		25° C.		38° C.		30° C.		25° C.	
	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.	ORGAN TEMP.	% VENOUS O_2 SAT.
Artery*	38.8	100	30.1	100	24.3	100	37.0	100	29.6	100	26.2	100
Mixed venous	-	54	-	66	-	79	-	38	-	56	-	75
Brain	34.5	55	29.6	62	25.2	73	35.7	33	30.0	66	25.2	78
Rt. auricle†	37.9	60	29.5	-	24.2	-	37.4	38	30.0	-	25.2	-
Liver	36.4	38	29.5	48	24.0	60	36.4	31	30.3	-	25.8	71
Kidney	37.3	72	29.9	75	25.0	-	38.0	44	30.3	79	25.3	83
Leg	36.0	44	31.0	48	26.5	50	37.9	39	29.6	59	25.0	87
Rectum	35.8	-	31.0	-	25.5	-	36.7	-	31.3	-	25.4	-

*Artery temperatures given are temperatures of the oxygenated blood just before entering artery.

†Right atrial blood samples with azygos vein ligated and both venae cavae occluded.

All temperatures recorded in centigrade. Organ temperatures represent averages of all animals perfused at the flow and esophageal temperature indicated.

These data also illustrate the close correlation between the mid esophageal temperature and the temperature of the other organs studied at both the 30° C and 25° C ranges.

Clinical Studies.—Studies on 27 patients undergoing open heart surgery with a combination of hypothermia produced by a heat exchanger and extracorporeal circulation have shown results similar to those obtained in the experimental animal. As in the dog, cooling and rewarming of man can be achieved in a matter of a few minutes and this has made it possible for us to proceed with intracardiac operations as usual, with the patients remaining euthermic until just before commencing the circulatory bypass. At this time, one of the patient's arteries is cannulated for arterial inflow and the inferior vena cava cannulated via a femoral vein for lower venous outflow. The heart-lung machine is then started at a low to moderate flow rate, and the patient perfused with blood cooled by its passage through the exchanger.

In this manner, hypothermia of 30° to 31° C can be achieved in the 5 to 7 minutes just prior to the cardiac portion of the operation during the time that final preparations are being made, such as inserting and connecting the superior vena cava outflow catheter, etc.

Data relative to perfusion rate, temperature during perfusion, and venous oxygen saturation on 6 representative patients, in whom this technique of hypothermia induced by a heat exchanger was employed for open heart surgery, are shown in Table II. It will be noted that in spite of low flow rates in 5 of these patients, hypothermia allowed for the maintenance of normal mixed venous oxygen values throughout the procedure.

TABLE II. CLINICAL DATA

DIAGNOSIS	FLOW (C.C./KG.)	FLOW L./M.²	ESOPHAGEAL TEMP. (° C.)	MIXED VENOUS O_2 SAT. (%) DURING PERFUSION
IAD	29	0.83	31	64 (5') 60 (10')
M. S.	26	0.95	29	75 (5') 70 (10')
IVD	51	1.5	32	61 (1') 59 (15') 60 (25')
IVD	42	0.93	33	78 (8') 79 (12')
IVD	60	1.34	30	84 (2') 74.5 (8')
IVD	35	0.94	29	63 (10') 70 (15') 63 (20')

(') = Minutes of perfusion after venae cavae were occluded.
M. S. = Recurrent mitral stenosis.

One advantage of combining hypothermia and extracorporeal circulation is illustrated by the clinical data shown graphically in Fig. 4. This patient's calcified and stenosed aortic valve was opened directly through a markedly dilated and thinned out aorta. For this portion of the operative procedure his temperature was lowered by the exchanger to 30° C. The operation and closure of the aortotomy required 6½ minutes of aortic occlusion. After this, the patient was rapidly rewarmed. However, a portion of the suture line in the friable aorta was inadequate and a terrifying leak developed through a small tear near the aortic base. When this occurred, the patient was quickly recooled to 32° C while the successful repair of the aorta, requiring a fur

12 minutes of aortic occlusion, was carried out. The patient suffered no sequelae and made an uneventful recovery. In the 27 clinical cardiac operations in which this method of producing hypothermia has been employed, we have had no difficulties or complications attributable to the procedure or apparatus.

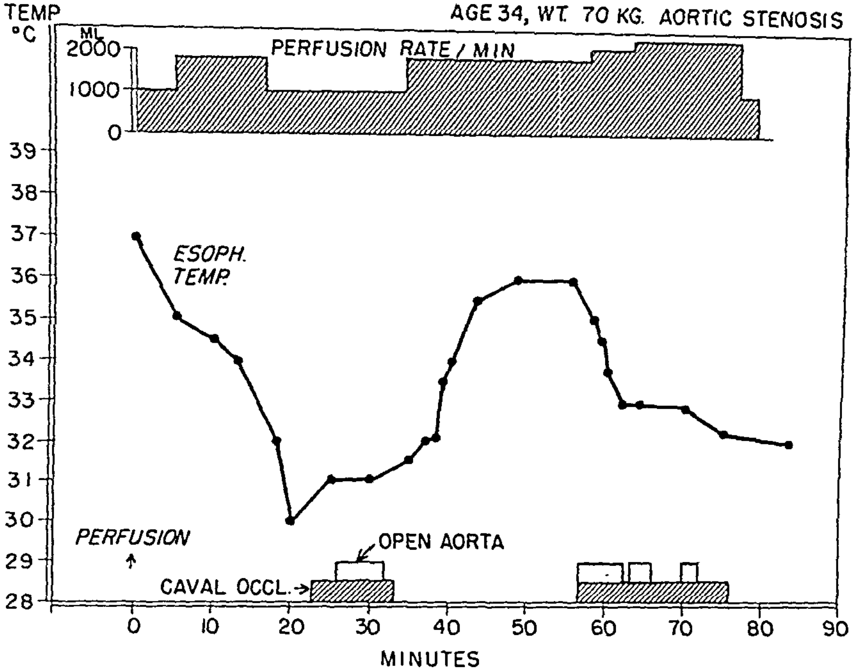

Fig. 4.—Temperature chart of a patient who underwent aortic valvulotomy for calcified aortic stenosis.

After closure of aortotomy, a serious leak and small tear in the aorta occurred. Patient was again rapidly cooled to 32° C. and the aorta clamped for 12 additional minutes. Uncomplicated postoperative course, no sequelae.

SUMMARY

Acute experiments on dogs combining extracorporeal circulation and hypothermia rapidly produced and corrected by a blood heat exchanger have been described. Studies were made of the cooling and rewarming velocities of various organs and tissues. It was found that the heart, liver, and kidneys cool and rewarm most rapidly and at essentially the same rate when hypothermia is produced and corrected by this method. The brain and mid-esophagus cool and rewarm at only a slightly slower rate. It was found that the mid-esophagus temperature most closely reflected the other vital organ temperatures. In both animals and man it has been possible to lower the temperature from 37° to 30° C. in a matter of a few minutes and to maintain evenly a chosen hypothermic temperature level to within 0.5° C. Rewarming from 30° to 35° C. has been accomplished at only a slightly slower rate than that of cooling. Oxygen saturation values of venous blood from the brain, right heart, liver, kidney, and leg in the hypothermic dog, maintained by a pump-oxygenator, show good relative correlation with the mixed venous blood oxygen values.

The effects of different perfusion rates at 38°, 30°, and 25° C upon the mixed and fractional venous oxygen saturation levels are also described

Hypothermia produced by a blood heat exchange method and its combination with extracorporeal circulation has been employed in 27 patients undergoing open heart surgery This clinical experience is briefly summarized and pertinent studies on a few of these patients discussed

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CEREBRAL BLOOD FLOW, METABOLISM, AND BRAIN VOLUME IN EXTRACORPOREAL CIRCULATION

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Among the complications of extracorporeal circulation are neurologic disturbances varying in severity from transient disorientation to progressive lethargy, coma, and death. A number of factors have been mentioned in the etiology of this syndrome, including hypoxia, caval obstruction from malfunctioning catheters, and cerebral embolism of bubbles, fibrin, and silicone.[1-14] The lack of knowledge on cerebral metabolism during cardiopulmonary bypass has made interpretation of such sequelae difficult, and these studies were undertaken to evaluate the effects of extracorporeal circulation on cerebral blood flow and metabolism, venous and spinal fluid pressures, and brain volume.

METHODS

Two groups of studies were performed. *Group I* was composed of 18 experiments in which cerebral flow was measured and studies of cerebral metabolism were performed. Brain volumes were determined in 10 animals in this group. *Group II* was composed of 21 experiments in which brain volume determinations were carried out. In 17, this measurement was made after periods of extracorporeal circulation and in 4 controls after Nembutal anesthesia only. In 10 animals, continuous measurements of arterial, jugular, and femoral venous and spinal fluid pressures were made during various conditions of extracorporeal circulation.

Cerebral blood flow was measured directly with a constantly recording magnetic rotameter by the method previously described,[3] except that in the last 9 experiments enucleation of the eye and coagulation of the orbital fossae were performed to eliminate anastomoses between internal and external carotid arteries.[15] By this method, cerebral flow was shunted from the proximal common carotid arteries through the rotameter to the brain through the internal carotid and vertebral arteries. Simultaneously, systemic arterial pressure and temperature were recorded. Simultaneous samples of carotid arterial and vertebral venous blood were analyzed for oxygen content, lactic acid,

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pyruvic acid, pH,* and glucose by standard methods.*[16-19] Usually two determinations were performed during each of four periods: (1) initial control, (2) high perfusion rate (in excess of 50 c.c./Kg./min.), (3) low perfusion rate (less than 50 c.c./Kg./min.), and (4) final control. Extracorporeal circulation was accomplished with a bubble oxygenator and Sigmamotor pump for periods ranging from 15 to 45 minutes. One hundred per cent oxygen was used in all experiments, but, in 7 instances, a 95 per cent oxygen–5 per cent carbon dioxide mixture was used for an additional period. At the conclusion of the experiments, the animals were sacrificed immediately for determination of brain weight and volume.

Venous pressures were monitored by means of capillary manometers attached to catheters in the external jugular and femoral veins. Spinal fluid pressure was determined continuously with a manometer connected to a large-bore needle inserted into the subarachnoid space in the lower thoracic region with the animal in the lateral decubitus position. Zero points for all manometers were taken at the level of the spinal needle.

Brain volumes were determined by a method slightly modified from that described by White and his associates[20] and subsequently used by Rosomoff and Gilbert.[21] This method involved measuring the actual volume of the brain by volumetric displacement and comparison with the volume of a paraffin cast of the reconstructed intracranial space. The percentage of intracranial space not occupied by brain tissue is referred to as the Differential Index of Brain Volume (D.I.B.V.). Percentage changes of brain volume and extracerebral space in terms of mean control value were then derived.

RESULTS

A. *Cerebral Flow and Metabolism* (Tables I and II).—

Perfusion rate: Perfusion rates ranged from 50 to 73 c.c./Kg./min. in the high flow experiments of Group I, such rates being attained in 12 animals. Low flow in this group ranged from 11 to 45 c.c./Kg./min., and was measured in 17 experiments. Perfusion rates in Group II ranged from 11 to 100 c.c./Kg./min., as various conditions of extracorporeal circulation were evaluated.

Blood pressure: Mean arterial blood pressure, as recorded in the femoral artery, in Group I ranged from 30 to 90 mm. Hg for the initial control values and from 20 to 120 during various periods of extracorporeal circulation. Blood pressure and perfusion rate were generally proportional. However, this relationship was not invariable as, at times, low pressures were recorded for higher rates of perfusion.

Cerebral blood flow: Cerebral flow was found to be directly proportional to the mean systemic blood pressure, both with and without extracorporeal circulation (Fig. 1). This exact relationship was best illustrated during periods of fluctuating pressure (Fig. 2). Perfusion rates were found to be an unreliable indicator of cerebral flow in as much as blood pressure and perfusion rate did not always change proportionally.

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*Clinical pH meter, Model 125-B, Photovolt Corp., New York, N. Y.

TABLE I. CEREBRAL FLOW AND METABOLISM

	INITIAL CONTROL			EXTRACORPOREAL CIRCULATION HIGH FLOW (> 50 C.C./KG./MIN.)			EXTRACORPOREAL CIRCULATION LOW FLOW (< 50 C.C./KG./MIN.)			FINAL CONTROL		
	NO.	MEAN	RANGE	NO.	MEAN	RANGE	NO.	MEAN	RANGE	NO.	MEAN	RANGE
Mean arterial pressure (mm. Hg)	18	65.6	30-90	12	72.5	45-135	17	53.7	20-120	12	74.0	20-110
Cerebral blood flow (c.c./100 mg./min.)	18	41	19-58	12	39	18-55	17	27	7-80	12	42	11-28
Cerebral oxygen consumption (c.c./ 100 mg./min.)	18	4.4	0.8-9.7	12	2.4	0.6-4.6	17	2.4	0.5-6.5	12	2.3	1.1-4.0
Arterial oxygen content (vol. %)	18	14.9	8.3-22.4	12	13.9	10.7-23.0	17	14.3	9.7-18.5	12	13.6	7.6-18.8
Venous oxygen content (vol. %)	18	4.1	0.9-14.6	12	7.2	2.4-14.8	17	5.4	1.4-13.5	12	7.4	0.7-14.5
Arterial-venous oxygen difference (vol. %)	18	11.0	2.0-17.5	12	6.6	2.6-11.0	17	9.0	2.7-14.6	12	6.2	3.5-10.5
Cerebral vascular resistance $\frac{P}{V}$	17	1.5	0.4-2.5	13	1.7	0.6-3.0	17	1.7	0.6-3.3	12	1.7	0.6-4.5
Temperature (degrees F.)	18	96	91-101	13	95.2	92-102	17	95.2	92-100	12	94.5	90.5-97
pH (vertebral vein)	9	7.57	7.3-7.78	9	7.48	7.1-7.74	9	7.48	7.2-7.8	9	7.34	7.1-7.74

Mean cerebral blood flow in 18 experiments was found to be 41 c c /100 Gm / min for the initial controls, 39 c c /100 Gm /min for the experiments with high flow rates, and 27 c c /100 Gm /min for the periods of low flow, and 42 c c /100 Gm /min for final controls

Cerebral A V oxygen difference Cerebral O_2 consumption was calculated as the product of the arteriovenous oxygen difference and the measured cerebral flow in cubic centimeters per 100 Gm per minute Cerebral oxygen consumption of 18 control animals averaged 4 4 c c /100 Gm /min However, oxygen consumption values for extracorporeal circulation, both with high and low perfusion rates, showed a marked drop with means of 2 4 c c /100 mg /min in both

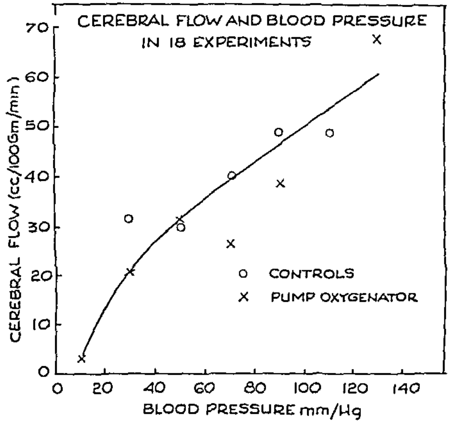

Fig 1—Graph showing the direct linear relationship between mean arterial blood pressure and cerebral blood flow This relationship applies for extracorporeal circulation and control periods

TABLE II CEREBRAL FLOW AND METABOLISM IN 6 EXPERIMENTS

	INITIAL CONTROL		EXTRACORPOREAL CIRCULATION (HIGH AND LOW FLOW)		FINAL CONTROL	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Cerebral flow (c c /100 Gm /min)	41	25 67	30	10 53	41	11 82
Cerebral oxygen consumption (c c /100 Gm /min)	4 8	3 3 7 2	2 2	0 4 3 1	2 2	1 9 4 0
Lactic acid (mg %)						
arterial	12 3	4 0 20 7	13 1	3 3 20 1	13 1	4 7 21 3
venous	14 3	4 3 28 3	14 9	4 0 27 2	12 4	5 2 24 3
Pyruvic acid (mg %)						
arterial	0 86	0 5 1 2	0 81	0 4 1 0	0 86	0 4 1 2
venous	0 88	0 6 1 1	0 88	0 3 1 2	0 82	0 3 1 1
Lactate/pyruvate ratio						
arterial	14 4	7 6 18 0	16 9	7 6 27 5	16 2	[illegible] 0 22 2
venous	17 0	7 5 31 5	18 8	1	17 9	[illegible] 26 2
pH (vertebral vein)	7 37	7 3 7 78	7 48		7 3	4

groups and persisting decreased oxygen consumption in the final control period (Fig. 3). This represented a decrease in oxygen consumption of 45 per cent of mean control values and occurred immediately after beginning of extracorporeal circulation. Decreased cerebral oxygen consumption was noted in all experiments at low rates of perfusion and in 9 of the 12 experiments in which high perfusion rates were attained, and resulted chiefly from a narrowed A-V oxygen difference due to increased venous oxygen content. This phenomenon was particularly evident at high perfusion rates (Fig. 4).

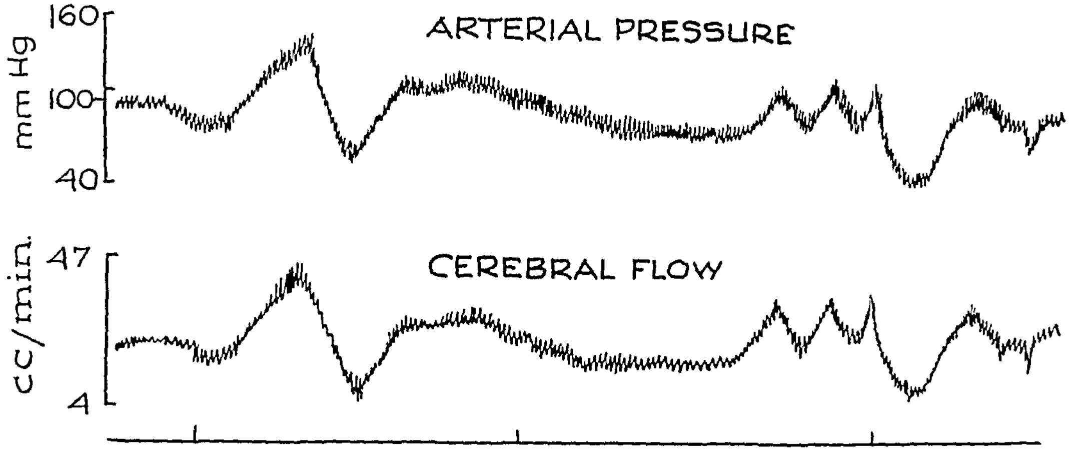

Fig. 2.—Drawing of a polygraph tracing of one experiment showing the exact relationship between arterial pressure and cerebral blood flow during extracorporeal circulation.

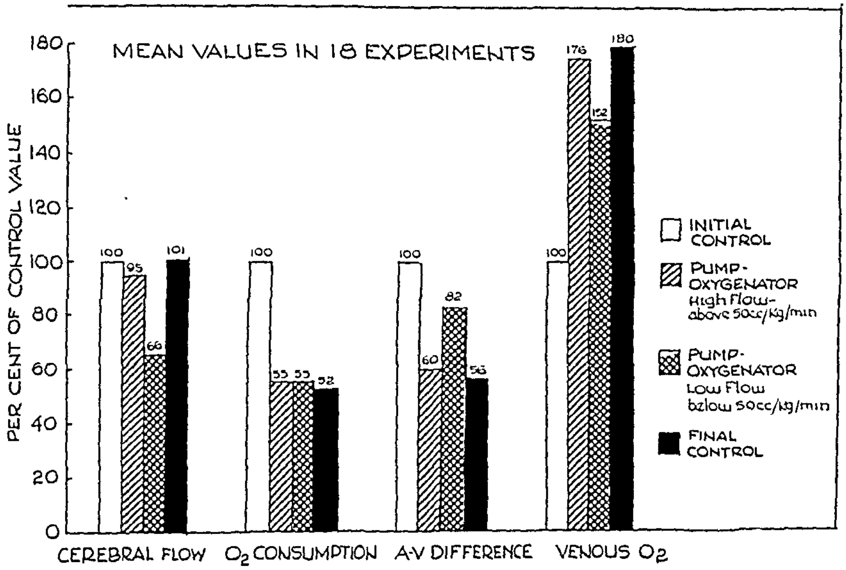

Fig. 3.—Diagrammatic representation showing that cerebral oxygen consumption decreased markedly with extracorporeal circulation despite smaller changes in cerebral flow, an effect resulting from decreased A-V difference due to increased venous oxygen content. This decrease in cerebral oxygen consumption occurred both at high and low perfusion rates, and persisted during the final control periods.

Lactic acid, pyruvic acid, and lactate/pyruvate ratio: Arterial and venous levels of lactic and pyruvic acids were determined in 6 experiments (see Table

II). There was no significant difference between control levels and levels during or after extracorporeal circulation. Venous levels of both lactic and pyruvic acid were usually higher than arterial levels. The lactate pyruvate ratio was markedly elevated in 1 experiment but no significant change from control values occurred with extracorporeal circulation.

Temperature. Temperature was maintained with electric heating pads or a circulating water blanket and was monitored in all animals of Group I and the majority of animals in Group II by a thermistor probe in the rectus abdominis muscle. Mean temperature for Group I controls was 96.0° F., temperature during extracorporeal circulation was 95.2° F. and during final control periods 94.5° F. Final control temperatures tended toward hypothermia, particularly following the longer periods of extracorporeal circulation.

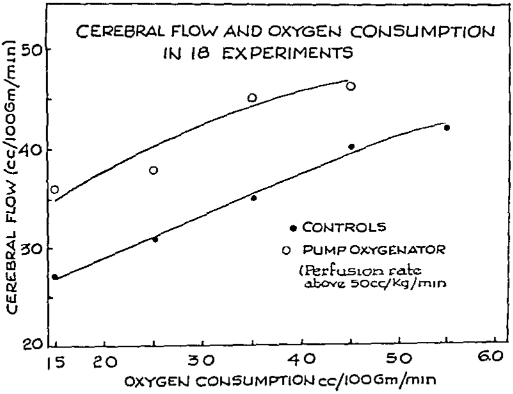

Fig. 4.—Graph showing cerebral oxygen consumption at varying rates of cerebral blood flow. At any rate of flow a lower cerebral oxygen consumption was noted during extracorporeal circulation than during control periods.

pH. This was monitored in 9 experiments of Group I, including the 6 experiments involving lactic and pyruvic acid determinations. Mean values for pH were 7.57 during the control period and 7.48 during extracorporeal circulation, without apparent difference between high and low perfusion rates. Final controls, however, showed a slight decline in mean pH to 7.34.

Glucose and pO_2. Arterial and venous glucose levels were determined in 8 experiments for controls and periods of extracorporeal circulation. A wide range of values was apparent without any definite pattern. Arterial pO_2 was monitored intermittently with a Beckman polarograph and was generally found elevated to 500-600 mm Hg.

Cerebral vascular resistance. Resistance (derived from the mean pressure minus mean rotameter circuit pressure drop of 10 mm Hg divided by cerebral flow per 100 Gm. brain per minute) showed no significant variation between control values and those obtained during extracorporeal circulation, mean values being 1.5 and 1.7, respectively. The mean value for low flow perfusion masked the definite decrease in calculated resistance observed in a number of experiments with low blood pressure levels. In the 7 experiments in which 5 per cent carbon dioxide was added after the initial run with 100 per cent oxygen, no decrease in mean calculated resistance was observed.

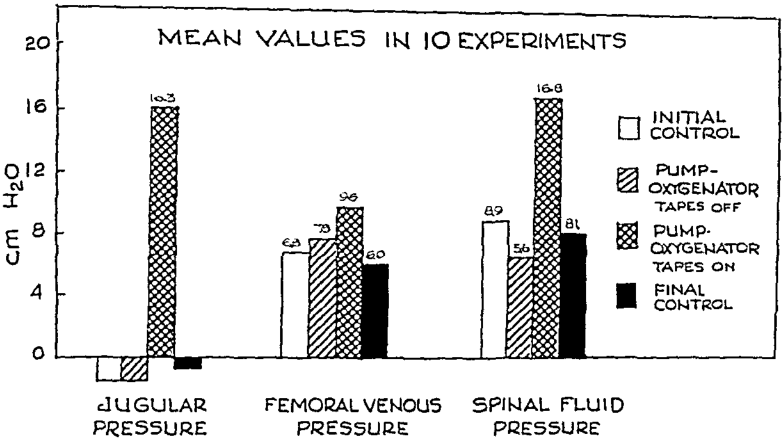

Fig. 5.—Diagram showing changes in jugular and femoral venous pressures and spinal fluid pressure during various periods of extracorporeal circulation.

TABLE III. VENOUS AND SPINAL FLUID PRESSURE CHANGES IN EXTRACORPOREAL CIRCULATION IN 10 EXPERIMENTS

	INITIAL CONTROL		EXTRACORPOREAL CIRCULATION PERICAVAL TAPES OFF		EXTRACORPOREAL CIRCULATION PERICAVAL TAPES ON		FINAL CONTROL	
	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Blood pressure (mm. Hg)	83	50-160	73.5	45-80	69.6	50-80	76.2	40-100
Jugular pressure (cm. H_2O)	Neg.	Neg.-5.5	Neg.	Neg.-5.0	16.3	Neg.-38	Neg.	Neg.-12
Femoral venous pressure (cm. H_2O)	6.8	2-11	7.8	2-11	9.6	6.5-19	6.0	4.6-11.5
Spinal fluid pressure (cm. H_2O)	8.9	4-13	5.6	2.0-12.5	16.8	5-30	8.1	3-19

B. *Venous and Spinal Fluid Pressures.*—

Venous and spinal fluid pressures were monitored in 10 animals of Group II (Table III, Fig. 5). Jugular venous pressures were usually negative in the control periods, although a few animals showed values from 2.0 to 5.5 cm. of water. At the start of extracorporeal circulation, without tapes around the venae cavae, venous pressures remained at control values; however, upon application of pericaval tapes, 4 animals demonstrated various degrees of caval obstruction as evidenced by rising venous pressure. This increase in pressure was observed in two instances despite adequate perfusion rate and blood pressure, and a lack of caval distention. Upon release of the tapes, jugular venous pressure returned toward control levels Femoral venous pressure increased very slightly above control values upon occlusion of the tapes and returned to control values when the tapes were removed

Control values for spinal fluid pressure ranged from 4 to 13 cm of water with a mean of 8 9 Upon commencing extracorporeal circulation, the mean spinal fluid pressure dropped to 5 6 as negative pressure was developed in the superior vena cava However, upon application of the pericaval tapes, animals showing elevated superior caval pressure also demonstrated rise in spinal fluid pressure that persisted until the jugular pressure returned to normal Small fluctuations in spinal fluid pressure were also observed with changes in perfusion rate and appeared to be related to systemic blood pressure

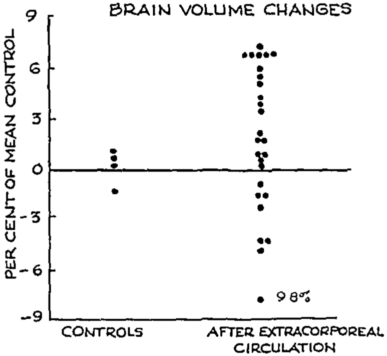

Fig 6—Brain volmes in 4 control animals and 27 animals after extracorporeal circulation in terms of per cent brain volume increase or decrease from mean control value Increased brain volume was noted in many animals following extracorporeal circulation A few showed decreased volume presumably due to hypothermia

TABLE IV BRAIN VOLUME AFTER EXTRACORPOREAL CIRCULATION

	NO	BRAIN VOLUME (C C)		CRANIAL CAPACITY (C C)		D I B V (%)		% CHANGE IN BRAIN VOLUME	
		MEAN	RANGE	MEAN	RANGE	MEAN	RANGE	MEAN	RANGE
Control	4	19 1	61 2 74 8	76 6	77 1 82 6	9 8	9 2 11 0	0	–1 1 0 88
After extracorporeal circulation	27	77 2	61 3 98 7	83 1	65 5 111 1	7 8	3 5 18 8	+2 3	–9 8 7 0

C *Brain Volumes*—

Four control animals showed a mean D I B V of 9 8 per cent In 27 animals, sacrificed from 15 minutes to 3 hours after extracorporeal circulation, there was a mean D I B V of 7 8, however, there were several hypothermic animals in this group and in these reduction in brain size was noted (Table IV, Fig 6) In terms of percentage change of brain size, there was a mean increase of 2 3 per cent over control values in animals after extracorporeal circulation The standard deviation of the mean control D I B V was ± 0 89

Using three standard deviations as limits of normal, 48 per cent of animals showed increased brain volume after extracorporeal circulation, and 11 per cent showed a decrease (Table V). Correlation between this increased brain volume and superior vena cava obstruction is suggested by the observation that all 4 of these animals manifested some degree of swelling. No correlation between increased volume and other variables in these experiments could be definitely established.

TABLE V. BRAIN VOLUME AFTER EXTRACORPOREAL CIRCULATION*

	NUMBER	% OF TOTAL
Normal	11	41
Increased	13	48
Decreased	3	11
Total	27	100

*Normal taken as ± 3 standard deviations of control mean.

DISCUSSION

The direct relationship between cerebral blood flow and arterial blood pressure and the relatively passive role of cerebral vascular resistance has long been appreciated.[8, 22] That this relationship should also apply to cerebral flow and blood pressure during extracorporeal circulation was suggested prior to confirmation by direct measurement. Furthermore, the poorer correlation of cerebral flow with perfusion rate of extracorporeal circuits is understandable in terms of differential changes in vascular bed resistance.

At low rates of cerebral blood flow, a linear flow-limited decrease in cerebral oxygen consumption was observed. However, decreased cerebral oxygen consumption, independent of blood flow, was also encountered and requires more detailed comment. This phenomenon, resulting from narrowed A-V oxygen difference due to increased venous oxygen content, was most marked at high flow rates. It also occurred at lower flow rates, although in these instances the effect was somewhat obscured by lower venous oxygen content resulting from increased extraction at the lower rates of cerebral blood flow. Explanation of this phenomenon must center around the three possibilities previously cited,[3] namely, altered tissue metabolism, impaired diffusion of oxygen to tissue, or uneven regional distribution of cerebral flow. It is of interest that changes in arteriovenous oxygen differences and of oxygen consumption during hypothermia show a comparable pattern.[23] Although temperature of the animals was continually monitored in the rectus muscle and although the nonflow-limited decrease in cerebral oxygen consumption occurred in preparations with stable, rising, or falling temperatures, the greater susceptibility of the brain to temperature changes[24] raises the possibility of disproportionate cooling of this organ during extracorporeal circulation. The blood from the oxygenator was perfused through a water bath at temperatures of 34° to 36° F., but actual blood temperature was not monitored, and the effect of perfusate below body temperature on the preparation cannot be excluded. One other factor to be considered is the abnormally high pO_2.

raising the question of oxygen intoxication[25] as a factor in the decreased cerebral oxygen consumption, although this remains a matter of questionable significance[26, 27] Furthermore, the decrease in oxygen consumption, observed in the experiments in which lactic and pyruvic acid levels were measured, failed to reveal any correlation with abnormalities in these substances (Fig 7) A lactate pyruvate ratio in excess of 15 is considered indicative of inadequate oxygenation of cerebral tissue[28-30] Several of our experiments showed ratios in excess of this figure, but there was no significant difference between controls and extracorporeal circuit determinations, and no correlation was noted between elevated ratios and oxygen consumption (see Fig 6)

Thus, the exact nature and possible pathogenicity of the decreased oxygen consumption during extracorporeal circulation is unclear The lack of correlation between brain volume increase and abnormal metabolism, either of oxygen or of lactate and pyruvate, is also of interest here

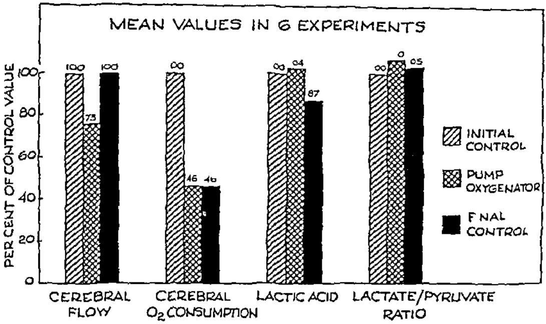

Fig 7—Graphic representation of venous lactic acid lactate pyruvate ratio oxygen consumption and cerebral flow The decrease in cerebral oxygen consumption occurred without alteration in lactic acid levels or lactate pyruvate ratios

Regarding venous and spinal fluid measurements, it was apparent that spinal fluid pressure was not a reliable index of brain volume changes, since *some animals with increased brain volume following extracorporeal circulation* had normal pressures This confirmed observations previously reported by White[20] The spinal fluid pressure elevations closely paralleled changes in superior vena cava pressure

Superior vena cava pressure, on the other hand, is important in patients with extracorporeal circulation, as pointed out by Kirklin[1] and Patrick[8] and their associates, since prolonged elevation results in an increased pressure gradient across the cerebral capillaries It is of interest that all 4 animals with measured superior caval obstruction showed increased brain volume This caval obstruction occurred in the presence of seemingly adequate perfusion rates and blood pressure in 2 of the experiments, and would otherwise have been unsuspected Adequate size and position of catheters as [illegible] and associates appear to be of crucial importance

Femoral vein pressure showed strikingly little change on tightening of pericaval catheters, an effect ascribable to the greater distensibility of abdominal organs, although identical catheters were used in superior and inferior venae cavae, and although the greater percentage of flow is by way of the inferior vessel.[31]

Brain volume changes noted herein are of interest in that 48 per cent of the animals following extracorporeal circulation showed significantly increased brain volume, presumed to be due to cerebral edema, as preparations were made according to White's exsanguinated-brain technique.[20] This is in accordance with the gross finding of cerebral edema in 60 per cent of animals dying shortly after extracorporeal circulation, reported by Clowes and co-workers,[2] and seems to correlate with fluorescein uptake evidence of blood-brain-barrier breakdown reported in animals after extracorporeal circulation by Hodges and associates.[13] Increase in brain volume has previously been shown to result *from anoxia and hypercapnia,*[20] *and decreases to result from hypothermia.*[21] Anoxia as such was difficult to measure, and no correlation was found between calculated cerebral oxygen consumption and increases in brain volume. Hypercapnia, on the other hand, can be eliminated as a factor in this high incidence of brain volume increase since, although CO_2 was not measured, the pH tended to be on the alkaline side, due to initial and final control hyperventilation on the mechanical respirator.

The exact significance of brain volume increase is unclear since 4 dogs with superior vena cava obstruction without extracorporeal circulation exhibited marked cerebral swelling after 24 hours in the absence of any signs or symptoms of cerebral damage, and since increased brain volume was found in 3 animals sacrificed immediately after 2 hours of open thoracotomy with positive pressure respiration. It is possible that increased brain volume is a part of the nonspecific response to trauma under a variety of circumstances, although it may also result from local damage.[32]

The failure of 5 per cent carbon dioxide to effect an increase in cerebral flow is difficult to interpret. It should be pointed out that although cerebral vessels in our preparation were still capable of responding, as evidenced by decreases in cerebral resistance at very low blood pressures, the preparation was by no means a physiologic one, requiring about 3 hours of surgery prior to control readings. Furthermore, the constrictor effect of high pO_2 may have prevented the vasodilatory effect of carbon dioxide.

SUMMARY

1. Cerebral blood flow during extracorporeal circulation was directly proportional to the mean systemic blood pressure and, at times, varied widely with perfusion rate.

2. Cerebral oxygen consumption decreased markedly during periods of low cerebral blood flow. However, decreased cerebral oxygen consumption during extracorporeal circulation was also observed during periods of adequate cerebral flow and resulted from increased venous oxygen content. Possible explanations of this phenomenon are discussed.

3 Lactic acid, pyruvic acid, and lactate pyruvate ratios showed no significant change from control values during extracorporeal circulation

4 Superior vena caval pressure and spinal fluid pressure varied together Marked elevations of superior caval pressure at times with apparently adequate perfusion rates and blood pressure were noted in 4 experiments

5 Approximately one half of the animals sacrificed shortly after extracorporeal circulation showed increased brain volume, including 4 animals with inadequate superior caval outflow

6 Increased brain volume may represent a nonspecific response in many instances, since it also occurred after procedures not involving extracorporeal circulation in animals showing no evidence of central nervous system damage

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(For Discussion, see page 530)

CLOTTING DEVIATIONS IN MAN DURING CARDIAC BYPASS: FIBRINOLYSIS AND CIRCULATING ANTICOAGULANT

Kurt N. von Kaulla, M.D. (by invitation), and Henry Swan, M.D., Denver, Colo.*

INTRODUCTION

Recent work[1] in our experimental and clinical departments has demonstrated that open heart surgery performed during hypothermia is sometimes accompanied by the fatal complications of hemorrhage and postoperative thrombosis. This work included a detailed investigation of the clotting mechanism in 9 patients undergoing such procedures as compared with 3 normothermic patients undergoing similar operations. In all of these patients the following determinations on the clotting mechanism were performed both at normothermia (37° C.) and at hypothermia (28° C.): (1) Recalcification time—a measurement of the over-all coagulability of the blood. (2) Prothrombin consumption—reflecting abnormalities in the first phase of clotting, i.e., thromboplastin formation. (3) Prothrombin activity—a measurement of the combined influence of the activity of prothrombin, factors V and VII (and inhibitors if present). (4) Thrombin time—the measurement of the activity of heparin and heparin-like inhibitors. (5) Fibrinolysis tendency—the tendency toward fibrinolysis which cannot be discovered watching "normal" clots, and (6) thrombelastography—a technique permitting a continuous recording of fibrin formation and fibrinolysis, and giving a good estimate of the firmness of the clot.

From these studies it was found that the clotting process of human blood is not impaired during procedures performed on the heart under hypothermia. However, it was noted that the clotting mechanism was as complete at 28° C. as it was at 37° C., and that there was a tendency for hypercoagulability to develop, particularly following the rewarming phase. The prolonged prothrombin time—a finding which is frequently seen in patients with congenital heart disease—oftentimes became more prolonged under hypothermia. Occasionally, a rare episode of severe hemorrhage was encountered. It was believed that this bleeding was due primarily to an increase in thrombin inhibitor and to the changes in vascular function associated with it. It was

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felt that these two factors represented the greatest danger in the development of such a bleeding episode, and that it was not due to the over-all reduction in the concentration of clot-promoting factors.

An occasional episode of clinical hemorrhage was noted following a cardiopulmonary bypass procedure; consequently, we were equally interested in

TABLE I

PATIENT	TEST	BEFORE ANESTHESIA	BEFORE PUMP	DURING PUMP			AFTER PROTAMINE		
S. H.	EU	360	113	(7) 56	(12) 13		(12) 19	(45) 37	
	TT	9.8	14.3				8.3	11.1	
	PL		129	137	81		104	83	
	Fg		304	194	246		256	210	
C. G.	EU	110	45	(7) 225	(12) 90		(10) 26	(15) 60	(60) 77
	TT	10.8	8.5					14.2	16
	PL		189	66	52		99	94	
	Fg		292	222	200		216	246	
A. R.	EU	360		(7) 27	(17) 13	(41) 14	(5) 18	(20) 9	(80) 120
	TT	11.5					22.3	28.8	7300
	PL		156	51	34	30	26		
	Fg								
J. B.	EU	112	36	(7) 15	(14) 10		(5) 22	(35) 75	(80) 78
	TT	16.1	18.7				7300	7300	18
	PL		198	55	46		49		
	Fg		210	118	144		137		
V. P.	EU	300	110	(7) 12	(20) 12		(7) 9	(37) 22	(60) 37
	TT	13.1	53				22	16	15.8
	PL		290	68	370		61	85	
	Fg		181	117	130		141	57	
D. W.	EU	230	120	(7) 12	(17) 8		(10) 11	(30) 10	(85) 160
	TT	17					31.4	16.7	25
	PL		295	38			49	37	
	Fg		352	165			395	229	
C. J.	EU	70	90	(9) 14	(16) 9		(11) 17	(35) 16	(110) 150
	TT	15	14				26.9	23.7	23.7
	PL								
	Fg								
D. K.	EU	60	90	(7) 50	(17) 30		(8) 20	(30) 34	(76) 107
	TT	16	25				20.2	20.3	26
	PL		162		82				
	Fg		212		193				
D. P.	EU	80	30	(7) 180	(20) 360		(5) 190		(60) 360
	TT	14.1	26.2				12		7300
	PL		108	53	75				
	Fg								
P. S.	EU	300	130	(2) 300	(12) 200		(5) 210	(30) 200	(60) 300
	PL		20				17	19.8	18.6
	PL		200	83	59		49		
	Fg		216	175	177		172		
L. N.	EU	150	40	(7) 40	(20) 38		(30) 34		(60) 55
	TT						215		17.8
	PL								
	Fg								

EU = Euglobulin lysis time. TT = Thrombin time. PL = Platelet count in thousands. Fg = Figrinogen value. ( ) = Minutes elapsed after beginning of bypass and administration of protamine, respectively.

studying the changes in the clotting mechanism that might be occurring during open heart surgery utilizing this medium of extracorporeal circulation. The purpose of this investigation was to determine the over-all influence that the pump and the procedures associated with it have on the mechanism of clotting and fibrinolysis. This is, essentially, a report of our findings in a group of patients with ventricular septal defects who underwent surgical repair under these conditions.

INVESTIGATIVE MATERIAL

A Gibbon type, fixed screen oxygenator with rotary DeBakey type pumps (Mark IV Apparatus) was employed in all of the patients undergoing this procedure. The clotting mechanism was studied by the determination of the following factors: (1) thrombin time, (2) fibrinogen values, (3) total platelet count, (4) euglobulin lysis time, and (5) thrombelastography. The euglobulin lysis time was determined by our own technique[7] which makes it possible to estimate rapidly the intensity of the fibrinolytic activity in normal and uncoagulable blood and, combined with the thrombin time determination, to detect whether or not uncoagulability is due to the absence of fibrinogen or to the presence of a circulating anticoagulant—the premise being that the euglobulin fraction can only clot in the presence of fibrinogen.

All of these determinations were made during the four major phases of the procedure: (1) before anesthesia, (2) before heparinization (prepump period), (3) after heparinization (the pump period with a record of the perfusion time at which the determination was made), and (4) after the administration of protamine (postpump period recording the time interval following the protamine administration and the determination). All of the data are summarized in Table I for the first 11 patients. The last patient was not included in this mastergraph since all of her determinations were performed in the postpump period, however, she will be presented and discussed in detail later in this paper.

Pertinent data including the age, weight, and sex of the patient along with the total time of perfusion on the pump, the presence or absence of hemorrhage, and the fate of the patient are presented in Table II.

TABLE II

PATIENT	AGE	SEX	WEIGHT (KG.)	PERFUSION TIME (MIN.)	HEMORRHAGE	FATE
1. S. H.	10	M	30.9	17.0	°	Survived
2. J. G.	7	M	23.0	16.0	°	Survived
3. A. R.	9	M	20.4	45.0	°	Died
4. J. B.	2	M	13.2	14.5	°	Survived
5. V. P.	11	F	23.5	22.3	°	Survived
6. D. W.	9	M	26.1	17.4	°	Survived
7. C. J.	4	F	15.0	15.0	°	Survived
8. D. K.	5	F	16.6	27.3	°	Survived
9. D. P.	3	M	12.6	22.0	°	Died
10. P. S.	4	F	12.4	23.0	°	Survived
11. L. M.	6	F	18.7	17.0	°	Survived
12. R. McC.	16	F	41.5	19.0	++++	Died

In addition, the effects of anesthesia, perfusion rate, and pH of the blood on fibrinolytic activity were investigated. Last, serial determinations of the plasminogen-activator in urine, called urokinase, were made before, during, and after the bypass procedure by a method developed recently by this laboratory.[3]

INTERPRETATION AND DISCUSSION

In our series of open heart procedures using this particular type of pump-oxygenator, we have been able to demonstrate the *presence of a circulating anticoagulant,* either alone or with *fibrinolysis.* These changes were so extreme in the last patient of our series that they were responsible for an uncontrollable and fatal hemorrhage following a technically satisfactory procedure. This patient, R. McC., was a 16-year-old schoolgirl who was operated upon for a ventricular septal defect with the use of the pump-oxygenator. Cardioplegia was difficult to obtain and, after the termination of a 19-minute bypass procedure, a heart block developed. Hemorrhage was noted after heparinization, and this rapidly increased in severity despite the administration of 188 mg. of protamine. There was a drop in the total platelet count from 209,000 to 61,000 and in the fibrinogen values from 211 mg. per cent to 155 mg. per cent. An additional 62 mg. of protamine proved ineffective, and specimens of blood taken at this time lysed in 15 minutes at room temperature—the fibrinogen value being 74 mg. per cent with a blood pH of 7.18. Intensive blood replacement totaling 17 units and the addition of 11.2 Gm. of fibinogen proved ineffective. Serial coagulograms of the recalcified citrated plasma along with the corresponding euglobulin lysis time were obtained; these determinations began about 1 hour after the administration of the fibrinogen or 100 minutes after the pump. The results of these determinations and their time interval after the initial coagulogram are graphically presented in the diagrams that follow.

Fig. 1 illustrates the serial coagulograms or thrombelastograms taken during the post-protamine period with the corresponding euglobulin lysis times. Coagulogram *A*, taken 60 minutes after the initial protaminization, reveals a very marked plasma lysis which began before the completion of the clot and a rapid euglobulin lysis. No coagulogram could be obtained at *B* (an hour later) because the plasma itself was uncoagulable, and the euglobulin fraction of this plasma lysed extremely rapidly. This demonstrates the presence of fibrinogen and fibrinolysis and, in respect to the uncoagulability of the plasma, the presence of an anticoagulant. Coagulograms *C* and *D* and their corresponding euglobulin lysis times were obtained after 1 and 2 additional hours, respectively, and after further treatment consisting of 8 Gm. of fibrinogen, 110 mg. of protamine, 200 units of ACTH, and concentrated erythrocytes. The absence of fibrinolysis is noted in *C* and *D* along with a delay in fibrin formation which was probably due to the large amounts of citrated blood that had been given.

The presence of an anticoagulant in this patient is further demonstrated by the data summarized in Fig. 2. The upper set of histograms illustrates the response of the thrombin time, a sensitive test for heparin type anticoagulants. A prolonged but measurable thrombin time is noted in specimen *A* taken 60 minutes after initial administration of protamine, whereas specimen *B* (obtained 1 hour later) is uncoagulable and induces complete inhibition of clotting when a 40 per cent sample of it is added to normal plasma. A 20 per cent and 30 per cent sample of this specimen containing circulating anticoagulant prolongs the thrombin time of normal plasma considerably. During this period, the uncoagulable plasma required 0.5 mg. per cubic centimeter of protamine for a partial normalization of its thrombin time. The thrombin time gradually returned to normal as shown by specimens *C* and *D*. The lower set of histograms represents the corresponding plasma lysis time. It is interesting to note the rapid lysis of specimen *A* and the uncoagulability of specimen *B*. This phenomenon is due to the presence of an anticoagulant, and not to the absence of fibrinogen. Twenty per cent and 30 per cent samples of specimen *B* were sufficient to induce rapid fibrinolysis of normal plasma, effectively demonstrating the combined appearance of circulating anticoagulant with fibrinolysis. Fibrinolysis has disappeared in specimens *C* and *D*.

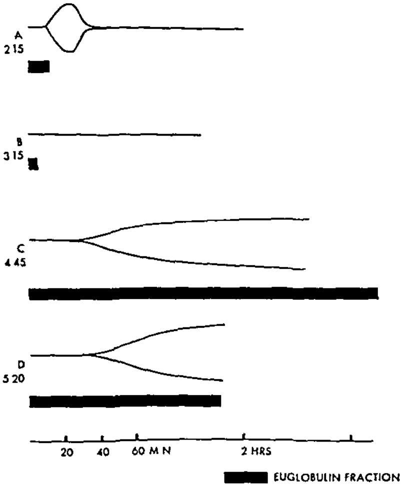

Fig 1

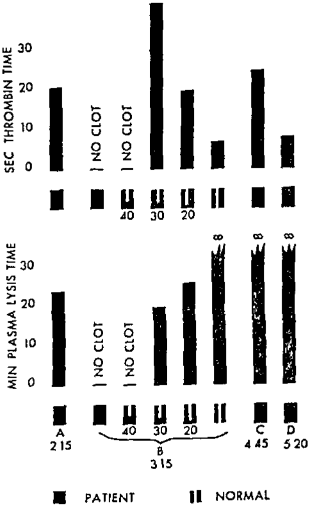

Fig -

It may be emphasized that fibrinolytic activity alone, even when considerably increased, does not necessarily cause hemorrhage. We have demonstrated this fact in a series of patients in whom we induced the same intensity and duration of fibrinolysis as was seen in our pump cases by means of pyrogens.[4] There was no evidence of bleeding in any of these cases. Significantly, there also was no evidence of a circulating anticoagulant in any of these induced cases. On the other hand, there is no doubt that the circulating anticoagulant is a contributing factor in the causation of hemorrhage. This anticoagulant is not a reactivation of the administered heparin but is a *new* anticoagulant produced by the body. Technically, its presence may interfere with the results of most clotting tests thereby simulating deficiencies that might not be present. It is, therefore, conceivable that some of the postulated cases of afibrinogenemia developing during surgery might have been cases attributable to the presence of a circulating anticoagulant.

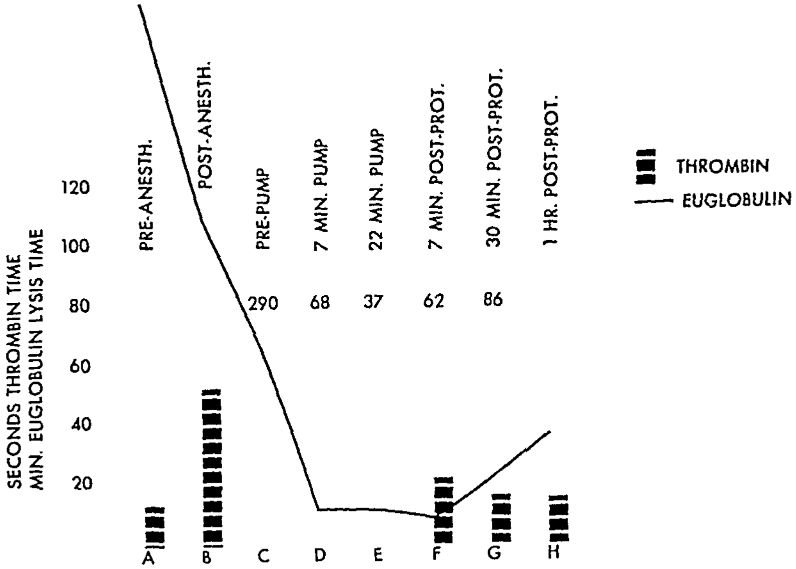

Fig. 3.

While searching for factors introduced by the operative procedure which might possibly be related to the presence of a circulating anticoagulant and/or fibrinolysis, we evaluated the following potential factors: (1) effects of anesthesia, (2) phenomenon of paracoagulation, (3) response to stress, (4) urokinase excretion, (5) pH of the blood, and, (6) perfusion rate. Our findings are presented in a brief summary and the pertinent data are illustrated.

1. *Effects of Anesthesia.*—Under anesthesia, the euglobulin lysis time demonstrates that there is an increase in fibrinolytic activity. This fact, in combination with the thoracic surgery necessary to prepare for the pump, increases lysis. This fibrinolytic activity is present before the pump is started and is, subsequently, further increased if the perfusion rate is low. However, it is not increased; in fact, it may even decrease, if the perfusion rate is high. The thrombin time reflects the activity of anticoagulants related to heparin. It cannot be measured during heparinization. Its changes are unrelated to the pump, and can occur at any time during the operation, i.e., before the pump, during the pump, or after the pump. Fig. 3 illustrates the thrombin

time and euglobulin lysis time of a patient (R. P., 10 years of age, with a ventricular septal defect; total pump time 22.5 minutes; no complication) who developed a transient anticoagulant of low titer after anesthesia (sample *B*) and a strong fibrinolysis tendency during the pump period and for a short time after termination of the bypass procedure. There was no evidence of bleeding. The histograms demonstrate the increase in the thrombin time after anesthesia and the inability to measure it during heparinization. This figure also presents the decrease in the total platelet count and the shortening of the euglobulin lysis time during the bypass procedure.

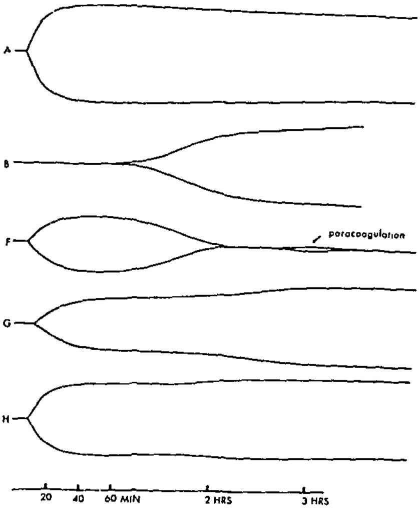

Fig. 4.

2. *Phenomenon of Paracoagulation.*—This phenomenon is adequately demonstrated in Fig. 4 which represents the corresponding coagulograms (recalcified citrated plasma) of the above-mentioned patient. It will be noted that no coagulogram could be obtained during heparinization. Sample *B*, taken at the time of increased anticoagulant titer, exhibits considerable delay in the onset of fibrin formation—illustrating the presence of circulating anticoagulant. Sample *F* shows plasma clot lysis to occur within 2 hours and also demonstrates the particular but not well-recognized phenomenon of paracoagulation—the re-formation of a clot after complete lysis. The postulated explanation of this phenomenon is probably incomplete formation of the first clot and the release of thrombin adsorbed on fibrin during fibrinolysis. This thrombin then clots the remaining unclotted fibrinogen. There is some delay in fibrin formation in sample *G* while sample *H* clots normally.

3. *Response to Stress.*—Fibrinolysis reflects a response of the organism to stress and one may theorize that its appearance is, among other conditions, facilitated if organs which are known to be rich in the activator of the fibrinolytic enzyme, such as the lung, prostate, or uterus, are operated upon.[5] This activator has to be released into the circulation in order to activate the plasminogen of the blood into active fibrinolytic plasmin. This release mechanism still remains in the realm of the unknown. The presence of a circulating anticoagulant was observed when difficulties were encountered during the operative procedure or complications, as cardiac arrest, developed during the postoperative period. This is demonstrated in Fig. 5 which represents the findings obtained in A. R. (a 9-year-old boy with a ventricular septal defect; 2 cardioplegias; poor heartbeat after discontinuing the pump, improved after second pump phase; total pump time 45 minutes; cardiac arrest postoperatively, chest reopened, cardiac massage; death). There is an extraordinary shortening of the euglobulin lysis time indicating a very marked increase in fibrinolytic activity. There is also a sudden rise in the thrombin time during the postpump period to indefinite values indicating the appearance of circulating anticoagulant of high titer. It is thought that a dysfunction of the vascular part of hemostasis may accompany the appearance of the anticoagulant or may actually be caused by it. At the present time, however, this postulation lacks verification.

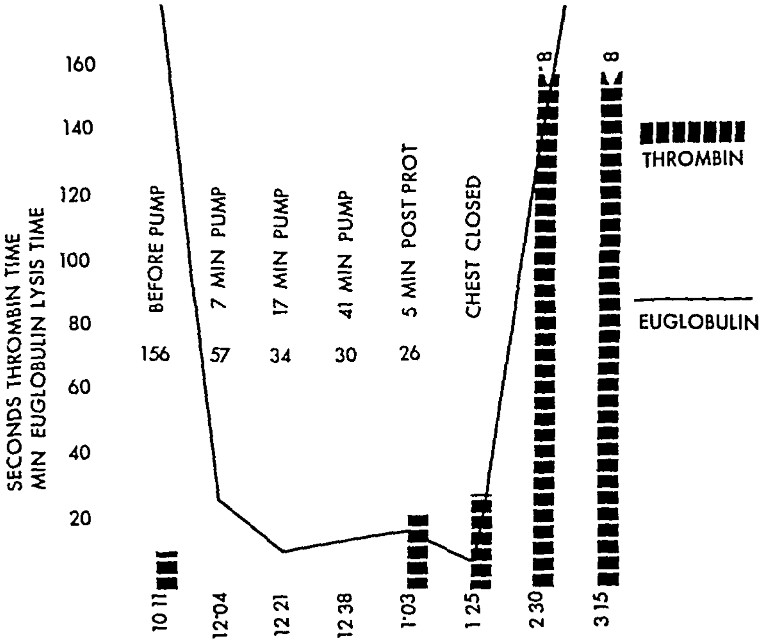

Fig 5.

4. *Urokinase Excretion.*—It has been observed that the fibrinolytic activity, which is not too uncommon during thoracic surgery,[6, 7 8] may be marked in some cases of open heart surgery with the use of the pump-oxygenator.

The enzymatic fibrinolytic activity in these patients is thought to be triggered by the release of a plasminogen activator which is then excreted in increased amounts in the urine It should be noted that circulation through the pump itself does not increase fibrinolytic activity of the blood Fig 6 presents serial determinations of the activator in the urine, called urokinase, in a patient, C J (4 year old girl with a ventricular septal defect, total pump time, 15 minutes, no complications) The euglobulin lysis time along with the trend of urokinase excretion, expressed in units of tyrosine released from casein incubated with urine activated plasminogen, is shown The specific gravity of the urine is indicated by the numerals above the histograms It can be clearly seen that there is a considerable increase in urokinase excretion shortly before the height of fibrinolytic activity Fig 7 (D K, a 5 year old girl with ventricular septal defect, total pump time 27 minutes, no complication) illustrates again that the peak of urokinase excretion is clearly related to maximum fibrinolysis Similar operative procedures without an increase in fibrinolytic activity failed to increase urokinase excretion during the procedure

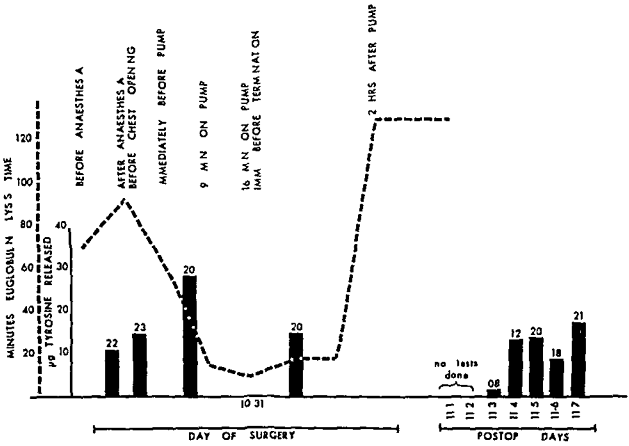

Fig 6

5 *pH of the Blood*—A low pH of the blood does not initiate fibrinolysis but enhances its intensity and duration This is demonstrated in Table III which represents a comparison of the pH of specimens with high fibrinolytic activity to those with low fibrinolytic activity during the four stages of the operation There is a considerable difference in the pH of both groups, particularly during the postpump phase The euglobulin lysis times were also arbitrarily divided into fibrinolytic and nonfibrinolytic ones and grouped

with their corresponding pH for the different stages of the operation. It can be seen that the longer the surgical procedure, the lower the pH of the fibrinolytic group as compared to that of the nonfibrinolytic group. This discrepancy amounts to 0.32 unit in the postpump period. The relationship of blood pH and peak fibrinolytic activity after the first protamine injection is also clearly demonstrated if the patients are divided into four groups of 3 individuals each with comparable lysis times, and the average times for each

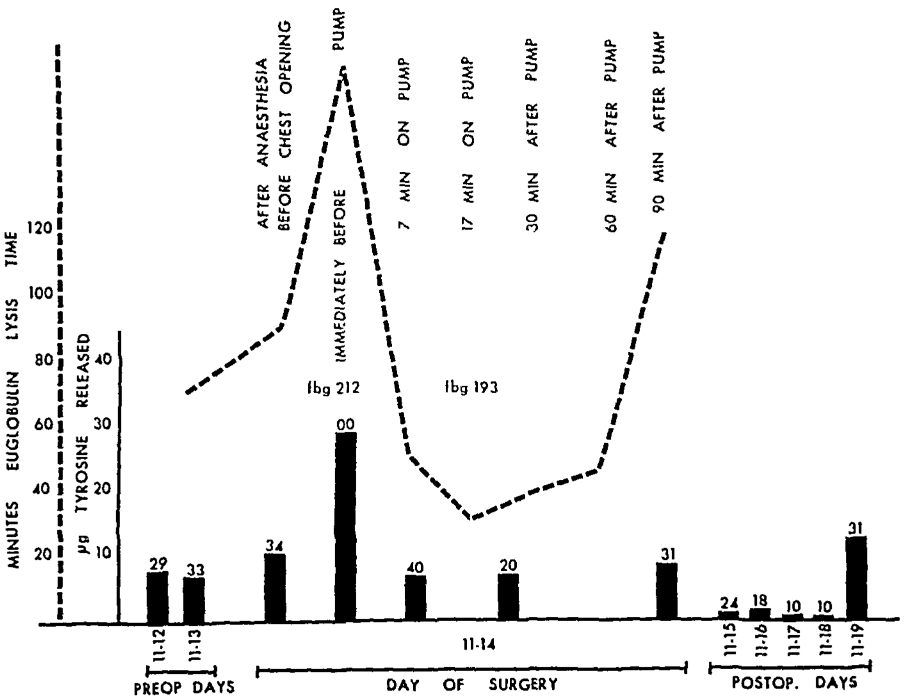

Fig. 7.

TABLE III

PUMP INTERVAL	NO. OF SPECIMENS	pH		LYSIS IN MINUTES	
		RANGE	AVERAGE	RANGE	AVERAGE
		Fibrinolytic Activity ++++			
Prepump	4	7.28 7.49	7.39	30 40	38
9-min. pump	4	7.31 7.50	7.42	12 27	18
16-min. pump	4	7.28 7.33	7.31	10 13	12
Postpump	7	7.01 7.39	7.18	5 22	15
		Fibrinolytic Activity ±			
Prepump	6	7.30 7.50	7.38	90 130	108
9-min. pump	6	7.35 7.65	7.46	40 225	142
16-min. pump	5	7.41 7.71	7.51	30 300	125
Postpump	5	7.35 7.71	7.50	26 210	99

group are plotted against the pH as shown in Fig. 8. The group exhibiting no lysis at this time has by far the highest pH. There is a direct relationship between the pH and the euglobulin lysis time

6 *Perfusion Rate*.—Closely related to the pH of the blood is the perfusion rate. Fig 9 demonstrates serial euglobulin lysis time determinations for a group of 8 patients (a) with a perfusion rate of 75 c.c./Kg./min., and for a group of 3 patients (b) with a perfusion rate of 190 to 200 c.c./Kg./min. Line *N* indicates the lower normal limit of euglobulin lysis time. Specimens with euglobulin lysis times below line *L* can be expected to exhibit lysis of their genuine clot at 37° C. within 24 hours or less. The influence of anesthesia on fibrinolytic activity[9] is shown clearly for group *B*, and the values are normalized during the bypass procedure, whereas, the fibrinolytic activity continues to increase in group *A*. There is only a minor increase in fibrinolytic activity in the well-perfused group during the most critical phase following the postpump protaminization. The interaction of protamine with the fibrinolytic system is not clear. Protamine has been described to inhibit the fibrinolysis, but there is evidence that protamine can enhance lysis both in vitro and in vivo.[10] Nothing specific could be found in this study that may be related to the appearance of a circulating anticoagulant.

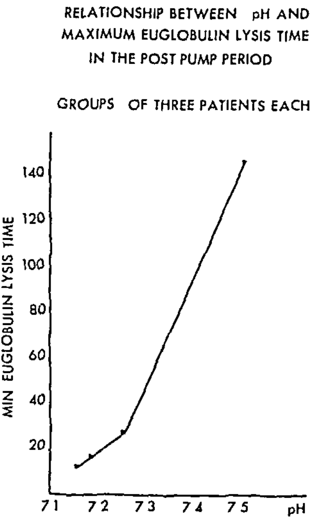

Fig 8

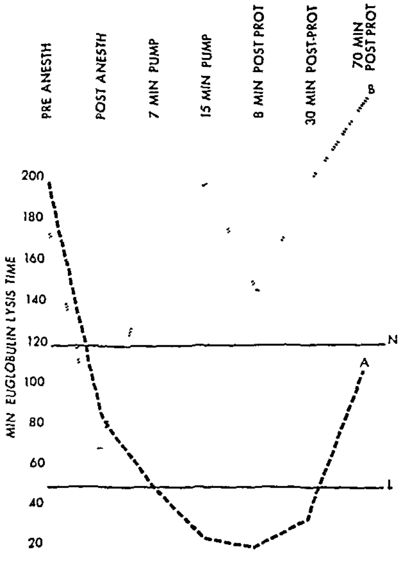

Fig 9

SUMMARY

In conclusion, we may state that a marked increase of fibrinolytic activity and the appearance of a circulating anticoagulant can considerably deviate the clotting mechanism during open heart surgery with the pump-oxygenator. This anticoagulant is not a reactivation of the administered heparin but is a new anticoagulant produced by the body. Fibrinolytic activity is enhanced by poor perfusion and a low pH of the blood, respectively. Neither fibrinolysis nor circulating anticoagulant themselves necessarily produce hemorrhage; however, their combination is dangerous.

We wish to express our thanks to Mrs. Edith von Kaulla for her technical assistance.

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(PAPERS BY KAY [PAGE 463], HODGES [PAGE 470], MUSTARD [PAGE 479], CLARK [PAGE 488], BROWN [PAGE 497], HALLEY [PAGE 506], VON KAULLA [PAGE 519], AND THEIR ASSOCIATES)

DISCUSSION

DR. H. BRODIE STEPHENS, San Francisco, Calif.—I should like to discuss the paper presented by Dr. Jerome Kay and Dr. Robert Anderson.

We (Drs. Orville Grimes, Benson Roe, Richard Gardner, and Peter Boudoures) have had the opportunity of utilizing the Kay-Anderson oxygenator in the laboratory for the past 3 months. In addition, it was our pleasure to observe Dr. Kay and Dr. Anderson using their oxygenator on a human patient with a very satisfactory result.

We were able to obtain only 13 survivors (dogs) in a total of 75 bypass experiments in which we used a bubbler-type oxygenator with a Sigmamotor pump (17.3 per cent survival). If the animal is alive and responding normally 7 days following the bypass, then we classify the animal as a survivor. The chief cause of death in this group of dogs was postoperative bleeding.

We were able to increase the survival rate in the dog with the use of the Kay-Anderson oxygenator. In 6 animals, a total bypass was carried out for 30 minutes; a ventriculotomy was not done Four of these animals survived In the next group of experiments, in addition to bypass for 30 minutes, right ventriculotomy was performed There were 22 experiments in this group with 11 survivors In an additional two experiments, potassium arrest was employed and both these animals expired on the operating table

The causes of death in these 15 dogs (total experiments numbered 30, therefore, 50 per cent survival in this group where the Kay Anderson oxygenator was used) were as follows (a) technical accidents, 4, (b) secondary bleeding, 4, (c) ventricular fibrillation with subsequent heart failure 3, (d) unexplained (occurring 48 hours postoperation) 3, and (e) cardiac tamponade, 1

We have been encouraged with the results in total heart lung bypass in the dog utilizing the Kay Anderson oxygenator We are impressed with the simplicity of the apparatus and thereby the ease of operation We are very much indebted to Dr Kay and Dr Anderson for their many kindnesses to us and for sharing with us their knowledge in the use of the Kay Anderson oxygenator

DR CHARLES P BAILEY, Philadelphia, Pa—I would like to report our early use of the autogenous lung rather than oxygenator for cardiac bypass, something like the method Dr Mustard has presented This technique was developed by Dr Gumersindo Blanco who heads our research laboratory Its perfection followed 18 months of laboratory work with us and, before that, 2 years at the University of Puerto Rico At last we have a practical method which has been used so far in 13 patients

This procedure is not as complicated as it may seem The blood is drained by gravity from the right atrium and then is delivered by the first pump to the pulmonary artery rather than into an oxygenator A large catheter with multiple holes is inserted into the left atrium and drains into a reservoir The second pump delivers this oxygenated blood into the femoral or peripheral artery An auxiliary oxygenator of the bubble type always is connected in parallel and is immediately available in case there is need for it We have needed it several times, particularly in the period of restoration of full cardiac action We have used this method of bypass chiefly for surgery of the aortic valve rather than in congenital cases While the lungs of aortic patients are normal, the lungs of patients with the tetralogy of Fallot may have a hypoplastic vascular bed which might not tolerate the entire circulatory flow Patients with ventricular septal defects may have severe pulmonary vascular damage which would impair pulmonary perfusion and blood oxygenation

In aortic stenosis, meticulous sculpturing of the diseased cusps may require considerable time Our average time has been more than 1 hour for definitive work on the valve itself Elective cardiac arrest alone does not protect the heart for so long a period We lost 5 of our 13 patients, we feel as a result of damage to the myocardium and anoxemia of the conduction system during surgery We could not control this consistently by retrograde perfusion of the coronary sinus probably because of the variations in the pattern of venous drainage of the heart However, by individual cannulation of the coronary arteries and pumping 200 c c per minute of oxygenated blood into them we are able to maintain the heart in good condition for a prolonged period It then will contract steadily during the definitive portion of the surgery

We believe that this is a proper and safe method to use for prolonged cardiac bypass in many types of cases, probably including many congenital ones While our experiences with animal surgery suggest that perfusion periods as long as 4 hours are safe and feasible, our longest human perfusion survival to date has been 2 hours and 20 minutes (140 minutes) Studies of the blood elements and chemical alterations constantly show less damage than that in conventional heart lung bypass of equal duration Apparently much more blood damage is produced in the oxygenator than in the pump

DR GEORGE H A CLOWES, Jr, Cleveland, Ohio—I want to [illegible] word about Dr Halley's interesting paper *For some time we ha* [illegible] vin [illegible] I m cause for death in animals, that have been perfused by any method, is progressive acidosis resulting from damage to the brain. During the last 2 years, data have been collected concerning the ability of the animal to control his pH, the arterial pH, in the postperfusion period. With your permission I would like to show one or two slides to illustrate this.

(slide) Here are presented data from three series of animals perfused for 1 hour of total bypass at high, medium, and low flow rates. It will be noted that the greatest degree of acidosis during perfusion occurred in those supported at low flow rates. In each group there was a further fall of arterial pH by the end of 6 hours postoperatively. The mortality rate thereafter was inversely proportional to the blood flow rate during the perfusion. By the following day all survivors had restored their arterial pH levels to within normal limits.

(slide) What does this mean? As shown by this slide, all surviving animals were able to maintain their blood pH postoperatively within pretty normal limits, whereas those that died just went on to progressively greater degrees of acidity.

(slide) In part this slide will show why those animals which died were unable to maintain a normal blood pH. In contrast to the survivors which maintained the blood CO_2 at or near normal levels in the postoperative period, the nonsurvivors showed increasingly higher blood carbon dioxide tensions. This failure to blow off CO_2 for the maintenance of normal blood pH probably is the result of grave damage to the brain and the inability to breathe adequately in the postoperative period. The brain is not functioning normally. Irreversible or temporary cerebral damage may be brought about by lack of oxygen as illustrated by certain work of Dr. Leland Clark and his associates or by any other type of trauma, such as emboli that will damage the circulation to the brain.

(slide) These experiments were done with a membrane oxygenator which we continue to use clinically with satisfactory results. Despite certain difficulties in assembling and the use of fluid sterilization, the advantages of a closed system make it effective and satisfactory in our hands.

DR. RALPH A. DETERLING Jr., New York, N. Y.—I appreciate this opportunity of discussing the paper by Dr. von Kaulla and Dr. Swan. Studies of fibrinogen by Dr. Louise Phillips in more than 20 patients with cardiopulmonary bypass at Presbyterian Hospital in New York confirm the conclusions presented by Dr. von Kaulla. With a 30-minute use of the DeWall oxygenator and Sigmamotor pump, we have noticed a 25 to 30 per cent fall in the normal value of fibrinogen from a normal of about 300 mg. per cent. In a few patients, there has been a sufficient fall in fibrinogen to warrant our giving the patient 4 Gm. of fibrinogen, despite a danger of inducing viral hepatitis. Occasional bleeding tendency postoperatively has usually been unrelated to the heparin factor. We are presently correlating all the factors that have been so well presented by the authors, and hope to add to this type of basic information in the near future. From the close correlation of data presented by Dr. von Kaulla with ours, it appears that certain changes in the clotting mechanism may well be independent of the type of pump-oxygenator apparatus.

DR. WILLIAM H. MULLER, Jr., Charlottesville, Va.—I would also like to discuss the paper by Dr. von Kaulla and Dr. Swan. Dr. Cecil Hougie, in our institution, the University of Virginia, has carried out a series of hematologic studies on 22 patients undergoing total bypass for open heart surgery. He demonstrated that excessive fibrinolysins were present in all these cases by the lysis of whole blood clots or the lysis of clots formed in tubes used in the titration of protamine sulfate. This technique is a very insensitive one, measuring only gross excesses of fibrinolysins, and the titers in these cases were therefore high, greatly exceeding those in patients undergoing cardiac operations not utilizing cardiopulmonary bypass. In 2 cases, the clots formed were very small, due, in part, to lower fibrinogen levels, and the lysins in these cases were more readily demonstrated by a simple modification of the fibrin plate method of Astrup. However, the lysins in most of these patients—and I think this is an important point—are not clinically significant or an important factor in hemostasis, since they were not necessarily associated with excessive bleeding They were very transitory in our patients and could not be demonstrated 1 hour after discontinuing the pump oxygenator, except in 1 patient where there was a prolonged thrombin time which was not corrected by the addition of protamine sulfate or fibrinogen Moreover, the plasma of this patient prolonged the thrombin time of normal plasma, showing that a circulating anticoagulant was present in the plasma of this patient Since the anticoagulant was not neutralized in vitro by protamine, it seems rather unlikely that it was heparin Protamine sulfate itself is an anticoagulant but this does not affect the thrombin time, and a possible excess of protamine therefore could not be the cause in these cases

Our findings were very similar to those of Drs von Kaulla and Swan The type of pump oxygenator does not seem to be of great importance in producing these changes because they used a screen oxygenator and rotary pump and we used the pump that Dr Clark demonstrated a few moments ago

DR CHARLES V MECKSTROTH, Columbus, Ohio —In connection with Dr Kay's paper, I have a short movie strip I would like to show with regard to the new filming technique which we think is preferable for those of you who have a stationary screen type of oxygenator As Dr Kay emphasized, one of the defects in this type of oxygenator is the dilution of blood by saline The usual technique is to follow saline with blood This produces a loss of two or three pints of blood and, secondly, a low hematocrit With our simplified technique there is no exact timing which needs to be observed, and it is essentially foolproof

(movie) Saline is pumped into the oxygenator which is then bubble free We then film with saline by removing the drain clamp from the oxygenator while the internal pump is in motion With the oxygenator set at this height and watching the flow of blood in the chamber, the saline will come down to this level over a period of 1 or 2 minutes Thus, there is no crucial time for taking off any clamps to minimize the loss of blood, and one can ascertain maintenance of the vacuum at the top of the oxygenator Two pints of blood are then added to replace the saline in the following manner After this, one adds at leisure four or five pints of blood for the perfusion cause for death in animals, that have been perfused by any method, is progressive acidosis resulting from damage to the brain. During the last 2 years, data have been collected concerning the ability of the animal to control his pH, the arterial pH, in the postperfusion period. With your permission I would like to show one or two slides to illustrate this.

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In 7 animals (Group I), perfusion was carried out without cardiac arrest or right atriotomy In 7 other dogs (Group II), the right atrium was opened immediately prior to a period of arrest and was not closed until effective contractions had resumed In the remaining 17 dogs (Group III), arrest was induced, but right atriotomy was either not performed (4 dogs, Group III A), or performed late in the period of arrest (6 dogs, Group III B) In 7 dogs (Group III C), the pulmonary artery was clamped as arrest was induced, and, in all but 1, the right atrium was opened late in the period of arrest

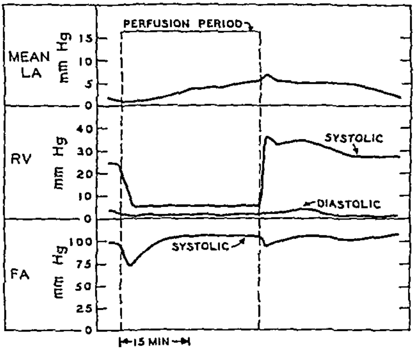

Fig 1—Pressures recorded from Dog No 2 Group I undergoing perfusion without cardiac arrest or atriotomy

RESULTS

Group I—In the 7 dogs undergoing perfusion without cardiac arrest or cardiotomy, mean left atrial and right ventricular pressures remained stable and low during perfusion There was an average left atrial pressure increase of 2 mm Hg with a rise in 1 animal to 6 mm Hg Following perfusion, mild, transient elevations in both mean left atrial and right ventricular pressures occurred in 2 dogs Fig 1, illustrating the pressure sequence in 1 animal, is representative of the entire group

There were no instances of ventricular fibrillation or post perfusion cardiac failure All 7 dogs in this group survived the immediate postoperative period and remained hemodynamically stable for the subsequent 1 to 2 hours in which pressures were monitored Control and post perfusion lung biopsies from 3 animals showed no evidence of pulmonary damage

Group II—In those 7 dogs in which right atriotomy was performed immediately prior to cardiac arrest, again, no significant pressure elevations were observed in either the right ventricle or left atrium during the period of arrest In 3 of the 7 dogs, ventricular fibrillation occurred when coronary flow

ELECTIVE CARDIAC ARREST DURING TOTAL BODY PERFUSION: THE RELATIONSHIP OF ELEVATED INTRACARDIAC PRESSURES DURING ARREST TO SUBSEQUENT MYOCARDIAL FUNCTION AND PATHOLOGIC PULMONARY CHANGES

John Ross, Jr., M.D. (by invitation), Joseph W. Gilbert, Jr., M.D. (by invitation), Edward H. Sharp, M.D. (by invitation), and Andrew G. Morrow, M.D., Bethesda, Md.

CARDIAC failure, ventricular fibrillation, and pulmonary parenchymal changes are not uncommon in dogs following elective cardiac arrest induced during total cardiopulmonary bypass. These complications of perfusion may also occur in patients in whom these techniques are employed. Intracardiac and pulmonary hemodynamics are markedly altered in the course of such procedures. The present study was undertaken in order to define more precisely the relationship of intracardiac pressure changes during perfusion and cardiac arrest to pulmonary damage and myocardial function following arrest.

METHODS

Thirty-one mongrel dogs were subjected to total cardiopulmonary bypass. Their weights ranged from 10.0 to 21.5 Kg., and averaged 15.0 Kg. The length of perfusion averaged 35 minutes and ranged from 25 to 51 minutes. A modified Melrose pump-oxygenator[1, 2] was employed to provide blood flows of approximately 100 c.c. per kilogram of body weight. A right thoracotomy was performed, and the superior and inferior venae cavae were cannulated through the azygos vein and right atrial appendage, respectively. The arterial cannula was inserted into either the femoral or the right carotid artery. A small catheter was then placed in the left atrium through a segmental pulmonary vein, and another was introduced into the right ventricle through either the jugular vein or a small incision in the right atrial wall. Throughout the perfusion and recovery periods, pressures were recorded simultaneously from the right ventricle, left atrium, and femoral artery, using Statham pressure transducers and a direct-writing oscillograph. In 24 of the 31 animals, elective cardiac arrest was induced by the potassium citrate method[3] for periods of from 12 to 17 minutes. When right atriotomy was performed, blood from the

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From the Clinic of Surgery, National Heart Institute, Bethesda, Md.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

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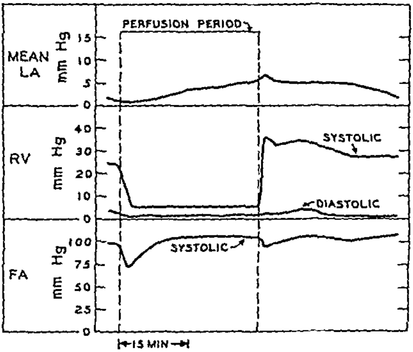

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TABLE I. GROUP II. DOGS IN WHICH A CONTINUOUS RIGHT ATRIOTOMY WAS MAINTAINED

DOG NO.	MEAN LEFT ATRIAL PRESSURE (MM. Hg)				RIGHT VENTRICULAR PRESSURE, S/D (MM. Hg)			
	BEFORE ARREST	AT END OF ARREST	AFTER RE STARTING	AFTER PERFUSION	BEFORE ARREST	AT END OF ARREST	AFTER RE-STARTING	AFTER PERFUSION
8	4	7	5	7	4/0	1	5/0	9/1
9	0	0	5	7	1/0	0	9/3	13/2
10	1	7	24	15	10/0	4	18/2	25/4
11	2	5	7	4	12/5	0	7/3	22/6
12	8	3	6	9	20/4	3	10/5	35/7
13	1	1	1	7	0	0	15/3	33/4
14	1	6	5	6	3/0	0	5/0	24/4

the unopened heart was resumed, both pressures showed further striking elevations and the heart became grossly distended in every instance. Ventricular fibrillation occurred in 2 animals, both of which died in heart failure following electrical defibrillation. Lung sections from the first 2 animals showed hemorrhage and edema in the biopsies obtained after perfusion (Fig. 4). A third animal spontaneously re-established an effective beat, while the remaining dog did so only with the aid of massage. Both of the latter dogs were chronic survivors and neither was found to have significant pulmonary damage.

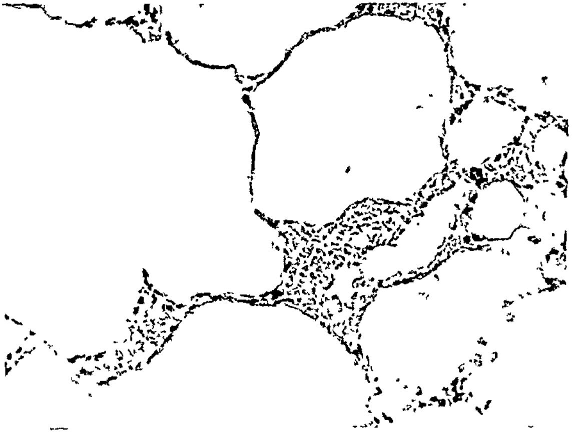

Fig 4.—Photomicrograph of the lung. Post-perfusion biopsy from a dog in Group III. Interstitial hemorrhage and intra-alveolar edema are demonstrated. (Hematoxylin and eosin; ×205, reduced 1/5)

Right atriotomy was performed in 6 dogs immediately prior to restoring coronary flow into the arrested heart (Group III B). Fig. 5 illustrates the usual pressure sequence during such an experiment. Prior to atriotomy, the left atrial and right ventricular pressures during arrest increased, as in the previous group, to an average value of 16 mm. Hg. Pressures in both sides of the heart usually returned to normal coincident with right atriotomy, although was restored. Electrical defibrillation was readily accomplished in all instances, although 1 animal exhibited persistent heart failure after defibrillation and subsequently died. The mean left atrial pressure of this animal was elevated to over 20 mm. Hg and mild edema without hemorrhage was evident in the post-perfusion lung biopsy. The lung biopsies in 5 other dogs were normal. Fig. 2 illustrates the typical course in 1 of these animals, and Table I summarizes the hemodynamic data from this group.

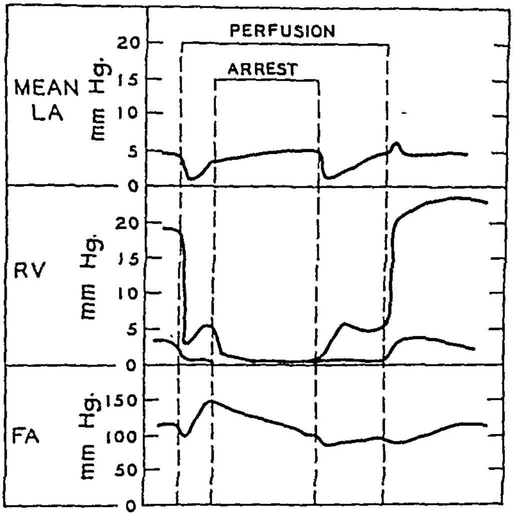

Fig. 2.—Pressures recorded from Dog No. 11, Group II, undergoing perfusion with cardiac arrest. Right atriotomy was performed before arrest and maintained until good cardiac action had resumed.

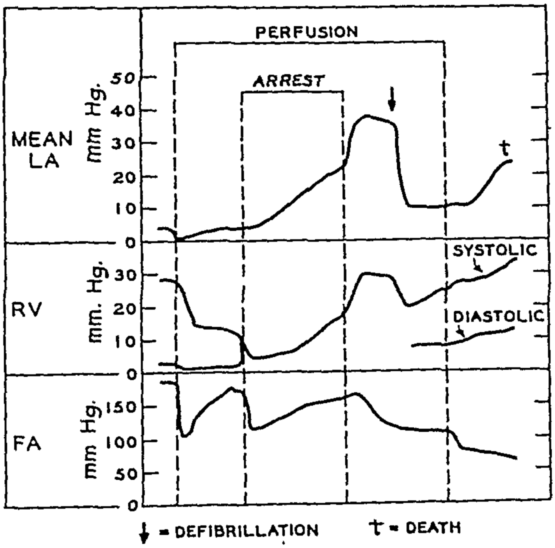

Fig. 3.—Pressures recorded from Dog No. 15, Group III A. No atriotomy was performed.

Group III.—In the 4 animals of Group III A, no cardiotomy was performed. Gradual elevations in mean left atrial pressure to an average value of 16 mm. Hg occurred during the period of arrest. Right ventricular pressure curves followed closely those of the left atrium (Fig. 3). When coronary flow into

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	BEFORE ARREST	AT END OF ARREST	AFTER RE-STARTING	AFTER PERFUSION	BEFORE ARREST	AT END OF ARREST	AFTER RE-STARTING	AFTER PERFUSION
8	4	7	5	7	4/0	1	5/0	9/1
9	0	0	5	7	1/0	0	9/3	13/2
10	1	7	24	15	10/0	4	18/2	25/4
11	2	5	7	4	12/5	0	7/3	22/6
12	8	3	6	9	20/4	3	10/5	35/7
13	1	1	1	7	0	0	15/3	33/4
14	1	6	5	6	3/0	0	5/0	24/4

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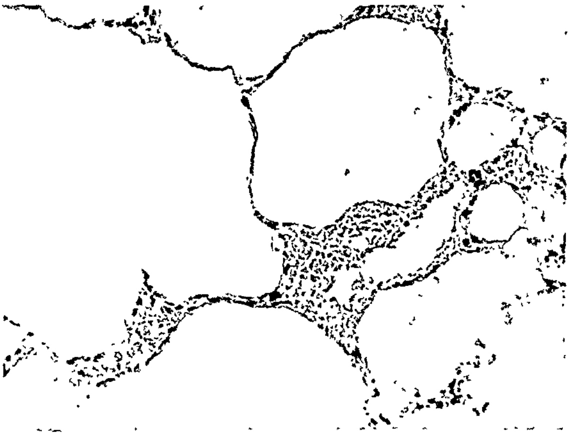

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TABLE II. GROUP III. DOGS IN WHICH RIGHT ATRIOTOMY WAS EITHER NOT PERFORMED OR DELAYED

PROCEDURE	DOG NO.	MEAN LEFT ATRIAL PRESSURE (MM. Hg)				RIGHT VENTRICULAR PRESSURE, S/D (MM. Hg)			
		BEFORE ARREST	AT END OF ARREST	AFTER RE-STARTING	AFTER PERFUSION	BEFORE ARREST	AT END OF ARREST	AFTER RE-STARTING	AFTER PERFUSION
A. No atriotomy	15	2	22	38	10	14/4	16	30	25/6
	16	5	20	76	5*	14/1	18	68	20/2
	17	4	13	44	5	18/3	12	48/24	30/4
	18	2	10	100	44	8/0	9	92	60/12
B. Delayed atriotomy	19	0	35	5	3	5/0	37	0	18/0
	20	3	12	28	40	20/3	13	32/11	40/9
	21	0	20	3	10	10/2	16	8/1	28/4
	22	0	6	18	20	13/3	7	22/5	40/8
	23	1	15	4	6	--	--	--	--
	24	0	15	15	13	--	--	20/4	25/8
C. P.A. clamped, late atriotomy	25	0	35	24	80	15/2	13	10/5	--
	26	1	20	3	3	8/3	12	5/0	25/5
	27	3	25	22	22	15/0	14	25/4	35/4
	28	4	17	12	12	--	5	20/3	19/5
	29	4	12	20	6	15/3	2	25/3	20/4
	30	0	24	38	48	8/2	10	23/4	60/16
	31	4	46	8	7	--	--	--	--

*Pressure following massage.

in several dogs a delay in the fall of the left atrial pressures occurred. This delay was associated with the highest left atrial pressures and could be obliterated by rendering the pulmonic valve incompetent.

Ventricular fibrillation occurred in 1 animal, and progressive heart failure *followed defibrillation. Of the remaining 5 dogs, 3 developed hemodynamic* evidence of persistent cardiac decompensation following perfusion. Postperfusion lung biopsies were obtained in 5 dogs. Sections from 3 of the dogs evidencing cardiac failure showed hemorrhage and edema.

In order to localize the origin of the blood accumulating in the right heart during arrest, the pulmonary artery was clamped coincident with aortic occlusion in 7 animals (Group III C). Typical pressure curves accompanying pulmonary artery occlusion during arrest are reproduced in Fig. 6. A separation of the left atrial and right ventricular pressure curves occurred. The elevations in right ventricular pressure were less than in the previous group, the average rise being 9 mm. Hg. The mean left atrial pressures, however, rose strikingly to an average value of 23 mm. Hg. These findings indicated that the major source of blood filling the right heart during arrest was retrograde flow from the pulmonary artery through a collapsed and incompetent pulmonic valve.

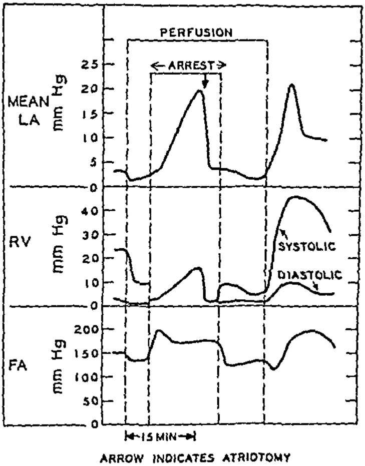

Fig. 5.—Pressures recorded from Dog No. 21 in Group III B. Right atriotomy was performed (at vertical arrow) prior to terminating cardiac arrest.

In 6 of these dogs, right atriotomy was performed immediately before the period of arrest was terminated. In the seventh dog, cardiotomy was not performed. Ventricular fibrillation occurred in 4 dogs, and in 3 of these, defibrillation was followed by cardiac failure. A fifth dog also developed cardiac failure. One of the five postperfusion lung biopsies showed significant pulmonary hemorrhage.

The hemodynamic data from the dogs in which no atriotomy or delayed atriotomy was performed (Group III) are presented in Table II.

Table III summarizes the results from all groups. In contrast to the dogs in Group III, in the control dogs and in those receiving a continuous right atriotomy, pulmonary complications were infrequent and death from early myocardial failure was uncommon.

TABLE III. SUMMARY OF POST-PERFUSION COMPLICATIONS

GROUPS	NUMBER OF DOGS	CARDIAC FAILURE	LUNG DAMAGE	DEATH IMMEDIATELY POSTOP.
I. No arrest				
II. Arrest with continuous atriotomy	14	1	0	1
III. Arrest with no atriotomy or delayed atriotomy	17	10	7	10

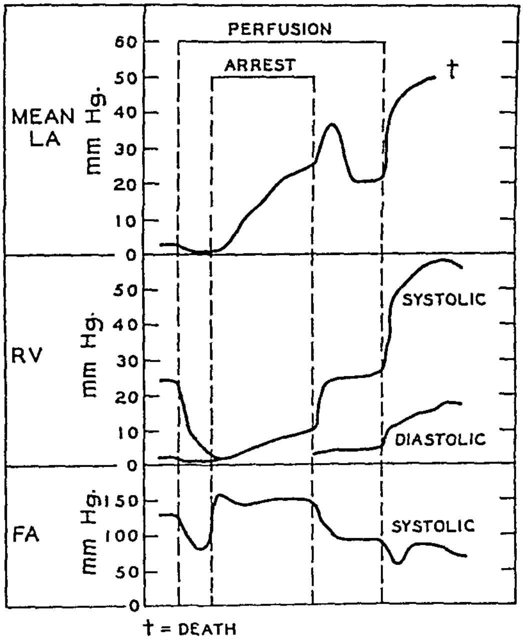

Fig. 6.—Pressures recorded from Dog No. 30, Group III C, in which the pulmonary artery and aorta were occluded simultaneously during cardiac arrest.

DISCUSSION

During total cardiopulmonary bypass, the bronchial arteries provide a continuous flow of arterialized blood to the lungs. Experiments have shown that when pulmonary artery pressure is low, blood from the bronchial arteries may flow into both the pulmonary arteries and veins.[4, 5] Thus, during cardiac arrest when pulmonary artery pressure is low, both the left and right sides of the heart receive this flow. The experiments described herein demonstrate a simultaneous rise in both right and left heart pressures during a period of arrest without cardiotomy. As long as the pulmonic valve remains incompetent, the two sides of the heart are in free communication through the pulmonary vascular bed. Retrograde flow into the right heart will thus prevent elevation of left atrial pressure if right atriotomy is performed early in arrest. If intracardiac pressures are allowed to rise during arrest, a subsequent right atriotomy will usually decompress the left heart, nevertheless, myocardial failure often occurs, indicating that even temporary dilatation diminishes the likelihood of re-establishing an effective beat. Following dilatation, recovery after electrical defibrillation is also less likely. This inadequate myocardial recovery is attributed to the change in diastolic fiber length imposed by dilatation of the heart during the arrest period.

It was observed that right ventricular pressures rose slightly even when the pulmonary artery was occluded, indicating an additional, although smaller, source of blood entering the right heart during arrest. Observations in isolated arrested hearts[5] have demonstrated that blood in the left heart and aortic root will perfuse the coronary arteries when the mean pressure in these areas exceeds 15 mm Hg. The return of such blood through the coronary sinus probably accounts for the pressure rise noted when retrograde flow from the lungs was prevented by occlusion of the pulmonary artery.

The microscopic changes in the lungs are more difficult to evaluate. Experiments producing elevation of pulmonary venous and arterial pressures by allowing bronchial artery flow into a lobe of the lung to which the pulmonary artery and vein had been ligated resulted in acute microscopic hemorrhage around the pulmonary capillaries. Such interstitial hemorrhage is not ordinarily seen following pulmonary edema alone, and its occurrence in the present series of animals suggested that a similar pressure mechanism during perfusion might be incriminated. However, a number of dogs not developing cardiac failure suffered marked acute pressure elevations without incurring detectable lung damage. Furthermore in most of the dogs demonstrating lung changes, cardiac decompensation was present by the time post perfusion biopsies were obtained. Such findings suggest that a combination of pressure elevation during arrest with subsequent cardiac failure may be necessary for the production of hemorrhagic lung damage. Others however, have found pulmonary hemorrhage to occur during the interval of arrest in animals having increased bronchial collateral flow that were subjected to pulmonary artery occlusion during arrest.[8]

In patients with congenital heart disease, and in some types of acquired disease, bronchial artery and pulmonary collateral flows may be greatly increased. It is evident that under these circumstances considerable magnification of the hemodynamic changes described herein will be observed. The present study demonstrates that a continuous right atriotomy during arrest will prevent intracardiac pressure elevations during cardiac arrest in the normal dog. However, as demonstrated in some dogs undergoing late atriotomy, right atrial decompression alone may not decrease left atrial pressure. In the face of high intrapulmonary pressures the pulmonic valve may remain competent. In this situation left heart decompression must be maintained either by a catheter placed through the pulmonic valve, or by direct left-sided cardiotomy. The practice of occluding the pulmonary artery and aorta together at the time of arrest prevents left heart decompression through the pulmonic valve, and would also necessitate drainage of the left heart.

With intracardiac defects accompanied by markedly increased collateral flow, drainage of the pulmonary artery, or left-sided cardiotomy, probably should be performed in all instances to provide decompression during the period following closure of the defect and resumption of effective cardiac contractions. Such decompression may also be indicated during the restoration of coronary flow after the open repair of valvular heart lesions. It is essential to avoid even brief periods of cardiac distention if the hazards of myocardial failure and its sequelae are to be minimized.

SUMMARY

Left atrial and right ventricular pressures were measured in 31 dogs subjected to cardiopulmonary bypass with and without elective cardiac arrest. When the heart was not arrested, there were no elevations in intracardiac pressures during the perfusion and recovery periods. The findings were similar in those animals undergoing arrest when a continuous right atriotomy was maintained. Marked elevations of left atrial and right ventricular pressures were recorded if atriotomy was not performed, or carried out late in the period of arrest. Pressure elevations were accompanied by distention of the heart, and subsequent myocardial failure was common; microscopic hemorrhage in the lungs occurred in some instances. Evidence is presented that the major source of blood returning to the right heart during arrest is from the bronchial arteries by way of the pulmonary vascular bed and an incompetent pulmonic valve. The importance of these observations in the clinical management of patients undergoing elective cardiac arrest is discussed.

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(For Discussion, see page 615)

PULMONARY LYMPH IN EXPERIMENTAL PULMONARY EDEMA

A Robert Cordell, M D (by invitation), Richard A Bahn, M D (by invitation), James C Stephens, M D (by invitation), and H H Bradshaw, M D , Winston-Salem, N C

THERE has been increasing interest in pulmonary lymphatic drainage in recent years as a result of the apparent rising incidence of bronchogenic carcinoma The major emphasis in this area has dealt with regional mediastinal lymphatics in relation to their surgical extirpation in conjunction with radical pneumonectomy for treatment of pulmonary malignancy The present study was stimulated by an attempt to understand the pathophysiology of edematous lungs as seen in patients on the thoracic surgical service The relationship of interstitial fluid or lymph to the development of the wet lung has been the subject of some investigation in the past Drinker and Hardenbergh[1] demonstrated to their satisfaction that the major portion of pulmonary lymph in the dog lung drains into the right lymphatic duct, which empties into the subclavian vein They were able to catheterize this duct in some animals and thereby sample pulmonary lymph

The present study was therefore outlined to investigate the relationship between pulmonary lymphatic drainage and the development of pulmonary edema in the dog

METHODS

A group of 10 dogs was used to study normal pulmonary lymphatic drainage In each animal the thoracic duct and the right lymphatic duct were exposed in the neck and cannulated with fine polyethylene tubing

The technique of right duct cannulation is tedious as might be expected from the delicate structure involved We have exposed the drainage system via a transverse incision in the neck just above the rib cage After identification of the external jugular vein, dissection is carried inferiorly to the junction of the jugular with the subclavian vein At this point the cervical lymphatic duct is seen coursing from a posterior position laterally to the vein junction where it opens into a cistern which empties into the venous system The right lymphatic duct usually exits from the mediastinum just inferior to the cistern

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Read at the Thirty eighth Annual Meeting of The American Association for Thoracic Surgery at Boston Mass May 16-18 1958 and empties into it from a caudad direction. This duct has been cannulated just inferior to the cistern using a P.E. 50 polyethylene tube sutured in place. Anomalies of the right duct are rather frequently seen but, in spite of the above-mentioned difficulties, about one half of the operated animals underwent successful cannulation, and an adequate flow of chyle-free lymph was obtained.

Three of these animals had previously been fed a fat meal to which Sudan III had been added. In 7 of the animals, sky-blue dye was sprayed into the endotracheal tube with duct catheters in place. A second group of 40 dogs underwent neck exploration, and 28 of these had successful cannulation of the right lymphatic duct. In 19 of these 28, we could demonstrate no apparent intercommunication between right lymphatic and thoracic ducts by means of fat feeding and differential dye study as mentioned below. Base line studies of pulmonary lymph were therefore completed on this latter group following which alpha-naphthyl thiourea (ANTU) dissolved in propylene glycol was injected to produce experimental pulmonary edema. Hourly samples of pulmonary lymph were collected until the time of death in these animals. These samples of lymph were studied for their electrolyte and protein contents.

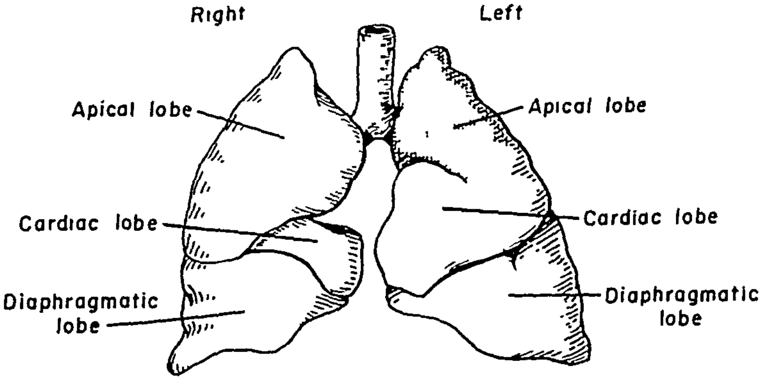

Fig. 1.—Drinker's work suggested that in 50 per cent of dogs the major pulmonary lymphatic drainage is via the right lymphatic duct, with only the left apical lobe (in black above) draining into the thoracic duct system.

RESULTS

Animals which had been given the high fat meal stained with Sudan III began to produce bright pink lymph from the thoracic duct in approximately 30 minutes. In these animals there was no coloring of lymph coming from the right duct. It would therefore appear that no mixing of lymph occurred in these animals in view of the differential dye study. On the other hand, when sky-blue dye was sprayed into the endotracheal tube, right duct lymph turned blue in 4 to 5 minutes. In 4 of the animals, dye appeared in low concentration in thoracic duct lymph in approximately 45 minutes.

These studies have shown that in approximately 50 per cent of dogs the major portion of pulmonary lymphatic drainage is via the right lymphatic duct. Drinker's findings, as shown in Fig. 1, are supported by these data. Animals for lymphatic study were therefore fed prior to operation, and only those from whom a steady flow of chyle-free lymph could be obtained from the right duct catheter were included in the final study. Normal serum and pulmonary lymph values in dogs from our laboratory for base line comparison are given in Table I.

When these animals were subjected to positive pressure respiration in the range of 25 cm. of water, an immediate increase in flow from the right duct catheter was noted. It was found that the average hourly lymphatic flow was usually doubled during the period of positive pressure respiration as shown in Fig. 2. There were no essential changes in the chemical content of this lymph from that in the normally respiring dogs.

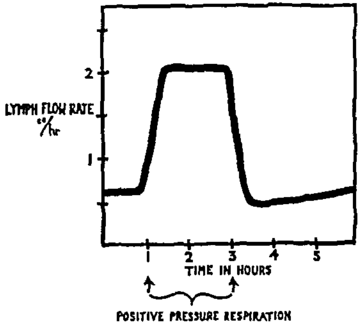

Fig. 2.—Positive Pressure Respiration and Lymph Flow. The effect of 25 cm. water positive pressure on the output of lymph from the right lymphatic duct.

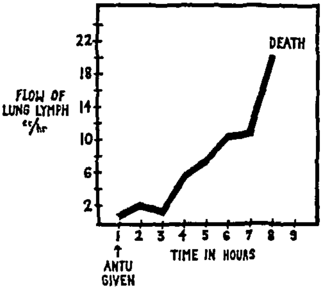

Fig. 3.—Effect of ANTU on lymph flow rate.

All animals receiving alpha-naphthyl thiourea developed fatal pulmonary edema, usually within 6 to 8 hours. The animals showed no ill effects of the drug until 1 to 2 hours before death when respiratory rate began to rise and increasing amounts of pink froth appeared in the endotracheal tube. At autopsy these animals showed ecchymotic, edematous lungs which exuded froth and watery fluid from the cut surface. Bilateral pleural effusions were usually present, but no other gross abnormalities were seen. Hourly lymph output from the right duct was collected from each animal, and these volumes averaged as shown in Fig. 3. Electrolyte and protein contents have been averaged and superimposed over the normal values as shown in Fig. 4.

An added constant finding was the gross appearance of red cells in the lymph with the onset of pulmonary congestion leading to edema and death.

TABLE I. COMPOSITION OF NORMAL SERUM AND LYMPH IN THE DOG*

	SERUM	LYMPH
Sodium (mEq./L.)	135-160	152
Potassium (mEq./L.)	3.7-5.8	4.2
Chloride (mEq./L.)	99-140	143
CO_2 (mEq./L.)	17-27	25
Protein (Gm. %)	6.1-7.8	3.25
Albumin (Gm. %)	3.1-4.0	2.43
Globulin (Gm. %)	2.0-3.3	0.9
pH	7.32-7.68	7.7

*This comparison of the electrolyte and protein content of serum and lymph in the dog shows their similarity except for lowered protein content in lymph.

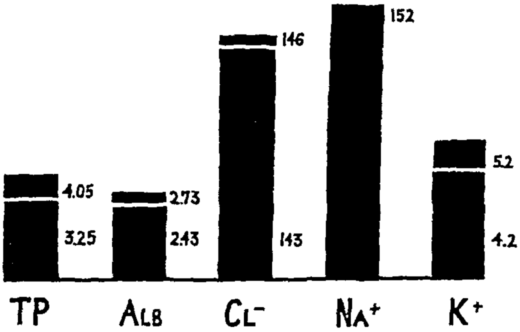

Fig. 4.—Content of Lung Lymph in Pulmonary Edema. Any changes from normal values are shown by separations in height of the columns.

DISCUSSION

From these experiments our results tend to corroborate Drinker's findings, in that approximately 50 per cent of our animals have been found to drain pulmonary lymph via the right lymphatic duct without apparent mixing with chyle from the thoracic duct. It was the feeling of that group that only the apical portions of the left upper lobe in the dog tended to drain, in a majority of animals, into the thoracic duct.

It would appear that right lymphatic duct cannulation permits the study of events in the interstitial spaces within the lungs by means of sampling pulmonary lymph. It by no means, however, represents total lymphatic drainage from the lungs in that the extensive pleural plexuses account for a significant portion of lymphatic drainage. Nevertheless, events within the pulmonary lymphatic system are apparently adequately reflected in the output from the right lymphatic duct.

Alpha-naphthyl thiourea has been extensively studied as a tissue poison by Richter,[9] Drinker,[1] Latta,[11] and others. It apparently exerts a rather specific effect upon the pulmonary vasculature by means of increasing permeability of the capillary bed In our hands, the dosage of 50 mg per kilogram of body weight was adequate to produce pulmonary edema within 6 to 8 hours without producing immediate death of the animal at the time of injection

It is interesting to note that electrolyte levels remained very similar in the lymph to that of the serum before onset of pulmonary edema Protein content in the lymph is about one half of that seen in the serum Comparatively little change occurred in the content of lymph throughout the pulmonary edema experiments in spite of the fact that great changes in output volume are obvious

In recent months, pulmonary edema has been produced in animals by means of creating large systemic-pulmonary artery shunts The pulmonary edema thus produced by means of increased pulmonary vascular flow and subsequent right heart failure is similar in most respects to that produced by alpha naphthyl thiourea Thus far, lymph changes due to increased pulmonary flow and eventual edema have closely paralleled those demonstrated by dogs given alpha naphthyl thiourea

CONCLUSIONS

1 In approximately 50 per cent of dogs, the major pulmonary lymphatic drainage is via the right lymphatic duct

2 The right duct can be catheterized in these animals and pulmonary lymph samples obtained

3 In the normal dog, sodium and potassium levels in pulmonary lymph approximate levels of circulating plasma while total protein content is approximately one half that of plasma

4 Positive pressure respiration tends to produce a uniform increase in output of pulmonary lymph from the right duct

5 In experimental pulmonary edema produced by intravenous injection of alpha naphthyl thiourea, a characteristic increase in lymph flow occurs while protein and electrolyte contents remain largely unchanged

6 It would appear that similar changes occur in animals subjected to arterialization of the lung

7 Right duct cannulation provides a method of pulmonary lymph study which should lend itself to other applications in the experimental laboratory One of these should be the timed collection of tagged malignant cells previously injected into the tracheobronchial tree Such a study should demonstrate the behavior of living cells with respect to their dissemination into the lymphatic drainage system

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(For Discussion, see page 615)

THE EFFECT OF POSITION ON PULMONARY VENTILATION

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INTRATHORACIC operations are usually performed with the patient in either a supine or lateral position. There are definite advantages to each approach. The posterolateral incision takes more time than the anterolateral approach (supine position), but it is very popular because it provides better exposure. There has long been a clinical impression that patients in the supine position tolerate anesthesia better and are more easily ventilated. Beecher and Murphy,[1] in a study of respiratory acidosis in patients undergoing thoracotomy, found that acidosis occurred more frequently when the lateral position was used. Later studies with mechanical respirators demonstrated that it was possible to prevent acidosis in these patients by providing adequate pulmonary ventilation.[4] It was the purpose of this study to determine whether the minute volume required to maintain adequate pulmonary ventilation in patients was greater in the lateral position than in the supine position.

PROCEDURE

The studies were carried out on 8 patients undergoing thoracotomy. Preoperative sedation consisted of barbituates the night before operation, repeated again in the morning and followed by Demerol and atropine. The patients were anesthetized with intravenous Pentothal Sodium, muscular relaxation was accomplished with intravenous succinyl choline, and the largest possible endotracheal tube was inserted. Anesthesia from that point consisted of endotracheal ether and oxygen (in one instance, nitrous oxide and oxygen). The endotracheal tube, which was cuffed, was attached to a closed circle type anesthesia machine. The patient was made apneic either by hyperventilation or by the use of succinyl choline and ventilation was provided by a Jefferson Ventilator.* Volume of ventilation was measured by a gas flow meter placed in the expiratory line of the anesthetic circuit. This meter has a flow rate capacity of 2.4 to 70 L. per minute with a resistance of less than 0.5 cm. of water at the higher flow rates. Pressures within the circuit were read from an aneroid type pressure gauge.

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An infrared absorption continuous carbon dioxide analyzer was used to follow the adequacy of ventilation throughout the operation. The accuracy of the analyzer was assured by a bank of calibrated tanks of carbon dioxide in oxygen ranging from 1 to 10 per cent. The concentration of carbon dioxide in these tanks, determined by the micro-Scholander technique,[8] remained constant until the cylinders were empty. A full calibration curve for the analyzer was established prior to the start of the operation and the calibration was checked periodically at the operating table. The machine gave remarkably constant readings over a period of weeks. A continuous partial sampling technique with a microcatheter cell was used as described by Collier and coworkers.[2] A sample of gas was drawn at a constant rate (600 c.c. per minute) from the end of the endotracheal tube. The gas was drawn through the analyzer beside the patient's head and the concentration of carbon dioxide was recorded on an Esterline Angus recorder located outside the operating room. From this tracing one could readily read the concentration of carbon dioxide in the inspired gas and the end expired gas. The latter was used to monitor the tension of carbon dioxide (pCO_2) in the arterial blood. In conscious patients, the tension of carbon dioxide in the end expired gas and in the arterial blood are approximately equal.[2] There is a greater discrepancy in patients under anesthesia but the difference is fairly constant and changes in one are mirrored by changes in the other.[5] An unchanged concentration of carbon dioxide in the end expired air is therefore considered a reliable indication of unchanged pCO_2 of the arterial blood.

After the patient was made apneic and ventilation begun, the volume of ventilation was gradually decreased until evidence of spontaneous respiratory effort appeared. Ventilation was then increased sufficiently to obliterate this voluntary effort. The concentration of carbon dioxide in the end expired gas at which this took place was noted and for the remainder of the procedure the pCO_2 was maintained as near as possible to that level.

A Cournand arterial needle was inserted into a brachial artery. Arterial blood for analysis was periodically drawn into oiled, heparinized syringes. The pH was measured using a Cambridge pH meter. Carbon dioxide content and oxygen content and capacity were measured by the technique of Van Slyke and Neill,[9] as modified by Goldstein and associates[3] to compensate for the pressure of ethyl ether. The tension of carbon dioxide in plasma (pCO_2) was calculated from the line charts of Van Slyke and Sendroy.[10]

The desired concentration of carbon dioxide in the end expired gas was maintained by changing the tidal volume; this in turn could be controlled by varying the difference between the inflation and deflation pressures. The mean pressure was kept between atmospheric and + 5 cm. of H_2O when the chest was closed. When the chest was opened the mean pressure was adjusted to give optimal expansion of the lung. The respiratory rate and the equal duration of inflation and deflation were unchanged throughout the operation. Measurements were made only after the state had become steady,[7] i.e., when the concentration of carbon dioxide in end expired air was unchanged for at least 5 minutes. This assured that the measured arterial pCO_2 was truly a reflection of that volume of ventilation.

Measurements were made while the patient was supine, after he was placed in the lateral position but before the chest was opened, at various times while the chest was open, and during closure.

RESULTS

Seven patients were operated upon in a lateral position (Table I) and 1 in a supine position. In 5 patients turning from the supine to the lateral position did not affect the efficiency of the ventilation. Both positions required approximately the same volume of ventilation to maintain the same pCO_2 (Fig 1). There was, however, some change in the pressures required to effect that volume. In some cases the same pressure produced the same volume, in others even less pressure produced the same ventilation after the patient was turned on the side.

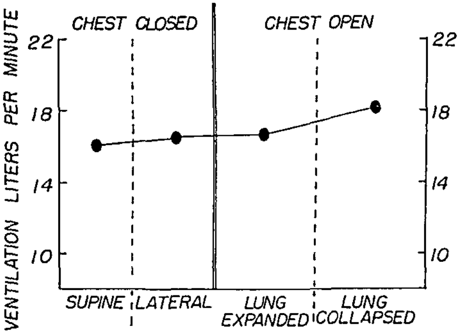

Fig 1.—Diagram of studies on Case 2.

In the other 2 cases there was an abrupt increase in ventilation required midway through the opening of the chest. These were associated with spillage of retained material from the diseased lung into the tracheobronchial tree. As an example, in Case 6 (Fig 2) considerable secretions from a trapped lobe spilled into the dependent lung midway through the opening of the chest and his ventilatory requirement immediately rose from 13 to 14.8 L per minute. By the time the chest was opened he needed 20.5 L per minute and this persisted through the period of closure and for 10 minutes after he was turned on to his back.

Opening the chest did not of itself significantly alter the ventilatory requirements. While the lung was fully expanded the efficiency was essentially the same, but when the lung was compressed there was a decrease in efficiency. An increase in volume of ventilation was required to maintain a steady pCO_2

The amount of change in efficiency due to compression of the lung was variable and in each instance was related to the local factors. In Case 4, the upper lobe was functionless because of tumor involvement. Consequently, compression of the upper lobe during the dissection of the upper mediastinum had very little effect on the ventilation. However, when the lower lobe was retracted there was a marked decrease in the efficiency requiring a considerable increase in volume. In Case 7, the lung was without function, consequently

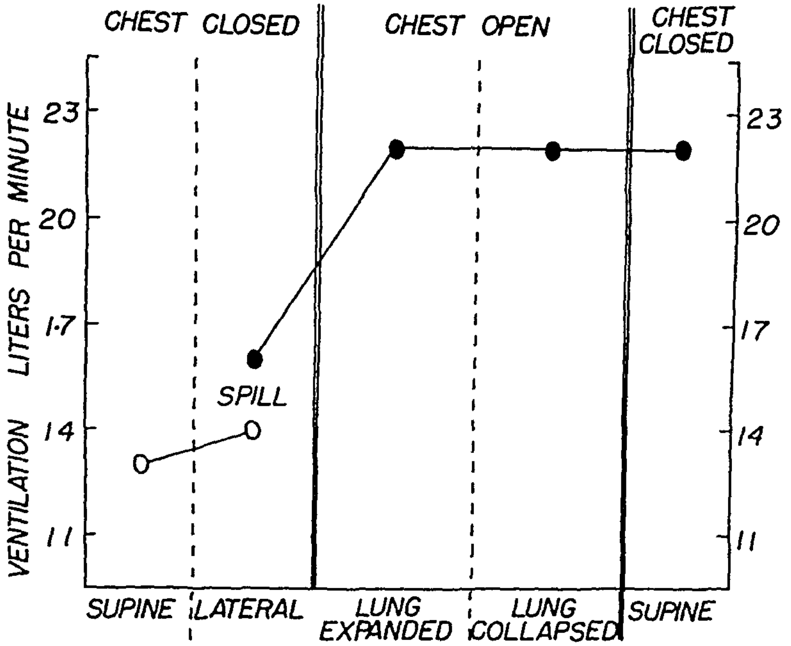

Fig. 2.—Diagram of studies on Case 6. Spillage of secretions during the opening of the chest interfered with ventilation. This persisted even after the patient was returned to his back.

TABLE I. RESULTS OF STUDIES OF 7 PATIENTS STUDIED DURING OPERATION IN A LATERAL POSITION

				LATERAL					
						CHEST OPEN			
		SUPINE		CHEST CLOSED		LUNG EXPANDED		LUNG COLLAPSED	
CASE NO.	OPERATION	VENT. (L./MIN.)	pCO$_2$ (MM. Hg)	VENT. (L./MIN.)	pCO$_2$ (MM. Hg)	VENT. (L./MIN.)	pCO$_2$ (MM. Hg)	VENT. (L./MIN.)	pCO$_2$ (MM. Hg)
1.	Exploratory thoracotomy	15.9	53	16.3	50	16.6	52	17.7	52
2.	Lobectomy	16.1	34	16.5	34	16.7	36	18.1	37
3.	Pneumonectomy	11.9	30	11.9	30	12.4	33	15.9	27
4.	Pneumonectomy	10.9	29	10.0	35	9.8	37	9.8	42
5.	Esophagectomy	19.6	22	18.3	21	19.5	20	18.5	32
6.	Exploratory	13.1	38	14.0	35†				
	thoracotomy	21.9*	34†	15.9‡	34	21.9‡	34†	21.9‡	34†
7.	Exploratory thoracotomy	13.0	35	14.5‡	44	13.8‡	50	12.9‡	48

*Measurements made at the conclusion of the operation when the patient was returned to the supine position.

†The underlined tensions were calculated from the analyzer record. The remainder were measured in the blood.

‡Measurements made after spillage of secretions.

compression of this lung did not change the efficiency of the ventilation In several other cases, likewise, it was noted that traction on the lung, particularly when working down near the main bronchus, greatly interfered with the flow of gas to the opposite lung Ligation of the pulmonary artery seemed to decrease the deleterious effect of compression of the lung However, we do not have sufficient evidence to make any definite statement regarding this point

The only patient who had an anterolateral incision (not included in Table I) required 17 L of ventilation per minute while the anterior surface of the hilum was being investigated When the lung was fully expanded, 14 8 L maintained the pCO_2 at the same level Because this was only an exploratory thoracotomy manipulation of the lung and vessels was not extensive Oxygen saturations were satisfactory throughout the operations but in most instances were lower while the lung was compressed

DISCUSSION

The major difference in ventilatory efficiency between the anterolateral and posterolateral approaches seems to be related to the amount of compression of the lung The hilar structures lie midway in the mediastinum while the lung on each side lies nestled in the thoracic bed Consequently with the anterolateral approach it is possible to work on the anterior surface of the hilum with considerably less compression of pulmonary tissue than is necessary with the *posterolateral incision Furthermore when the patient is in the* lateral position the lung is more likely to collapse from its own weight because of its position in relation to the bronchus

It is not our purpose to discourage the use of the posterolateral approach We are well aware of the improved exposure available and use this incision in the majority of our intrathoracic operations However, in order to obtain satisfactory ventilation in this position, one must compensate for the effect of compression by periodically allowing the lung to expand

SUMMARY

The ventilatory requirements of patients undergoing thoracotomy were measured while they were in the supine position, and in the lateral position before and after the chest was opened

Efficiency of ventilation was not affected by the lateral position but was decreased by compression of the lung The greater need to compress the lung in the lateral position is pointed out The importance of periodic expansion of the lung is stressed

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(For Discussion, see page 615)

AORTIC HOMOGRAFT REPLACEMENT OF THE MAIN PULMONARY ARTERY

George Robinson, M D (by invitation), Philip Glotzer, M D (by invitation), Marvin Gilbert, M D (by invitation), and Elliott S Hurwitt, M D ,
New York, N Y

THIS SERIES of experiments was initiated following a pulmonary thromboendarterectomy in a patient suffering from chronic thrombosis of the pulmonary artery A brief review of the literature and report of 2 additional cases of this clinical syndrome has been presented[1] In the analysis of previously reported cases of chronic thrombosis of the pulmonary artery, it became apparent that in some cases the obstruction was situated in the main pulmonary artery or one of its major branches and might therefore be amenable to surgical therapy Two surgical approaches to the problem were then considered First as reported previously, the surgical method employed was open removal of the thrombotic material from the involved vessels under conditions of inflow occlusion of the heart This paper further expands the therapeutic approach to pulmonary artery obstruction by the presentation of two additional techniques for complete replacement of the pulmonary artery[3]

No previous reference was found in the literature describing a surgical technique for the placement of grafts in this area, nor was any information obtainable regarding the ultimate fate of aortic homografts in the pulmonary artery It is the purpose of this paper to present the methods employed to replace the pulmonary artery and its bifurcation, with a preliminary report of the results Long term studies on the ultimate fate of these grafts will be presented at a later date[4]

METHOD

Adult mongrel dogs were anesthetized with veterinarian Nembutal or Pentothal Sodium administered intravenously Tracheal intubation was performed and the thorax was opened through a bilateral fourth intercostal space incision with transection of the sternum The lungs were rhythmically inflated with oxygen by means of a mechanical respirator In the first few

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From the Henry L and Lucy Moses Research Laboratories the Surgical and Medical Divisions the Montefiore Hospital New York City

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experiments the aortic grafts were prepared 24 hours before operation and stored at –20° C. until used. The majority of the experiments were performed employing fresh rather than preserved grafts.

Various segments of the donor aorta were tried to obtain a satisfactory fit for the graft. These included the ascending aorta and brachiocephalic vessels, as well as the distal aortic bifurcation and iliac branches. The best-fitting graft was obtained from a relatively long, straight segment of the thoracic aorta. This was applied across the anterior surface of all the great vessels, employing an end-to-end anastomosis to each pulmonary artery. When using the pump-oxygenator and elective cardiac arrest as an adjunct to the graft procedure, the end of the main pulmonary artery was anastomosed to the side of the graft. When not employing cardiac bypass, this anastomosis was done in side-to-side fashion.

A. METHOD 1. *Technique of Pulmonary Artery Replacement With the Use of the Extracorporeal Pump-Oxygenator.*—

The main pulmonary artery and its major branches were completely mobilized out to the origins of the first segmental arteries. The azygos vein was doubly ligated and divided to facilitate the dissection of the right pulmonary artery posterior to the superior vena cava. Tapes were placed about the venae cavae intrapericardially. The venae cavae and the femoral artery were cannulated preparatory to employing the pump-oxygenator. Heparin was administered in the amount of 1 to 1.5 mg. per kilogram of body weight. Two to 3 mg. per kilogram of protamine sulfate was given intravenously at the conclusion of the procedure.

A bubble oxygenator of the DeWall type was employed. The right main pulmonary artery was ligated at its origin and the distal segment withdrawn from behind the superior vena cava. An end-to-end anastomosis was then performed between the distal end of the pulmonary artery and one end of the graft. The suture material was 5-0 arterial silk with an atraumatic needle,* placed with a simple running stitch. During this phase of the operation, respiratory function was carried on by the unobstructed flow to the left lung. After completion of the anastomosis, cardiopulmonary bypass was started and elective cardiac arrest was accomplished with the Melrose technique. The supravalvular portion of the main pulmonary artery was then transected and an ellipse of tissue removed from the side of the graft at the site of election for the anastomosis. An end-to-side anastomosis was then performed.

At this point, the use of the oxygenator may be terminated and the right lung perfused with blood going through the right limb of the graft. For convenience the procedure was usually completed by performing the left anastomosis with bypass, and continued cardiac arrest. This results in only several minutes' additional operating time with bypass while the final phase of the procedure is completed (Fig. 1).

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*Supplied through the generosity of the Ethicon Suture Laboratories, Inc., New Brunswick, N. J.

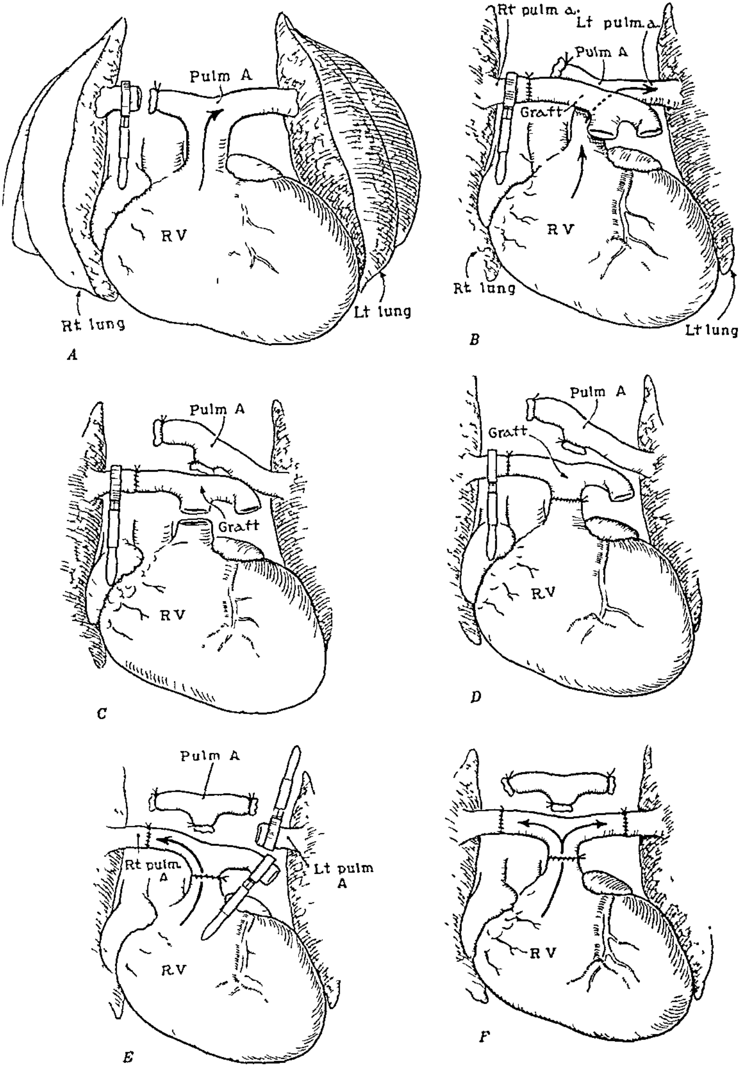

Fig. 1.—Diagrams of Method 1 for replacement of pulmonary artery. Cardiopulmonary bypass is essential for steps *C* and *D* (see text).

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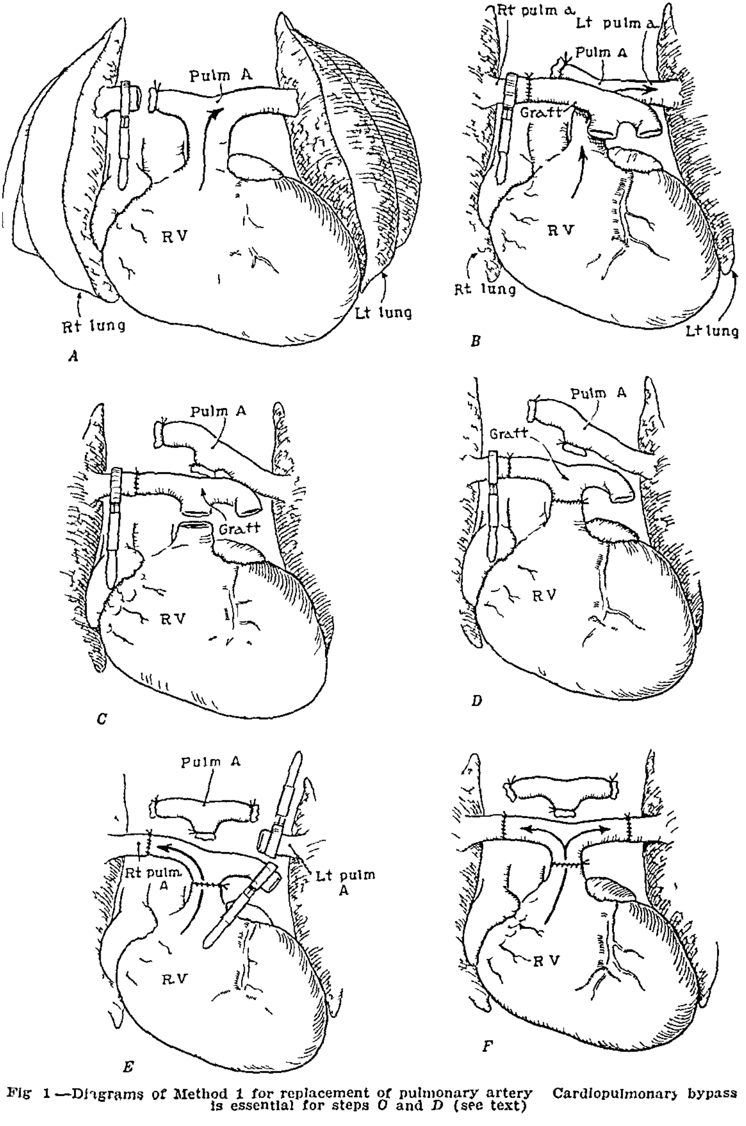

Fig 1 —Diagrams of Method 1 for replacement of pulmonary artery Cardiopulmonary bypass is essential for steps *C* and *D* (see text)

Results: Seven experiments of this type were performed. There were no long-term survivors. Two of the experiments were conducted early in our experience with this experiment, as well as early in our experience with the pump-oxygenator. The last 5 experiments were performed recently, after considerably more experience with the placement of the grafts and more experience with the use of the oxygenator.

The last 5 animals all resumed a normal sinus rhythm at the conclusion of the operations, but all died within 12 hours. Hemorrhage was the cause of death in all cases. This complication has not otherwise been a feature either of our experimental or clinical experiences with the pump-oxygenator. One dog had a dilatation of the right ventricle upon completion of the experiment, indicating some obstruction in the outflow of the right ventricle, but this occurred in our longest survivor.

B. METHOD 2. *Pulmonary Artery Replacement Without the Pump-Oxygenator.*—

Only as much of the anterior wall of the main pulmonary artery as necessary for the placement of a nontraumatic partial occlusion clamp was cleared of fat and visceral pericardium. The right and left main pulmonary arteries were then mobilized from their origins to the first segmental branches. The azygos vein was doubly ligated and divided. An ellipse was removed from the wall of the aortic graft and an anastomosis performed between the graft and the excluded segment of the anterior wall of the main pulmonary artery. The lungs are normally perfused during this portion of the procedure. The right main pulmonary artery was then ligated at its origin, divided, and the distal end removed from behind the superior vena cava. End-to-end anastomosis was performed with the right limb of the graft. While this was being done, the left lung was normally perfused. Upon completion of the right anastomosis, the left limb of the graft was occluded, and the right lung was perfused through the graft. The left pulmonary artery was then ligated at its origin and its distal end anastomosed to the graft (Fig. 2).

Results: Twenty-five experiments were performed in this group, with 6 deaths on the operating table. Of the 19 surviving animals, there were 14 who lived 4 weeks or more. Two dogs are now 15-month survivors with bilateral replacement of the pulmonary arteries. Modification of the experiment was necessary in 6 cases because of small size of the graft or poor condition of the animal. In these 6 instances, only one pulmonary artery was replaced with a graft to the main pulmonary artery. In the latter group there were 4 survivors of 4 weeks or more.

A total of 6 animals died on the operating table of the following causes: (1) malfunction of the endotracheal tube, (2) hemorrhage, (3) short inadequate sized graft, (4) acute dilatation of the heart and cardiac arrest, (5) immediate thrombosis and occlusion of the graft, and (6) ventricular fibrillation.

There was an opportunity to examine 7 grafts that had been in situ for 4 weeks or more. There was minor thrombosis in one of the grafts and in one

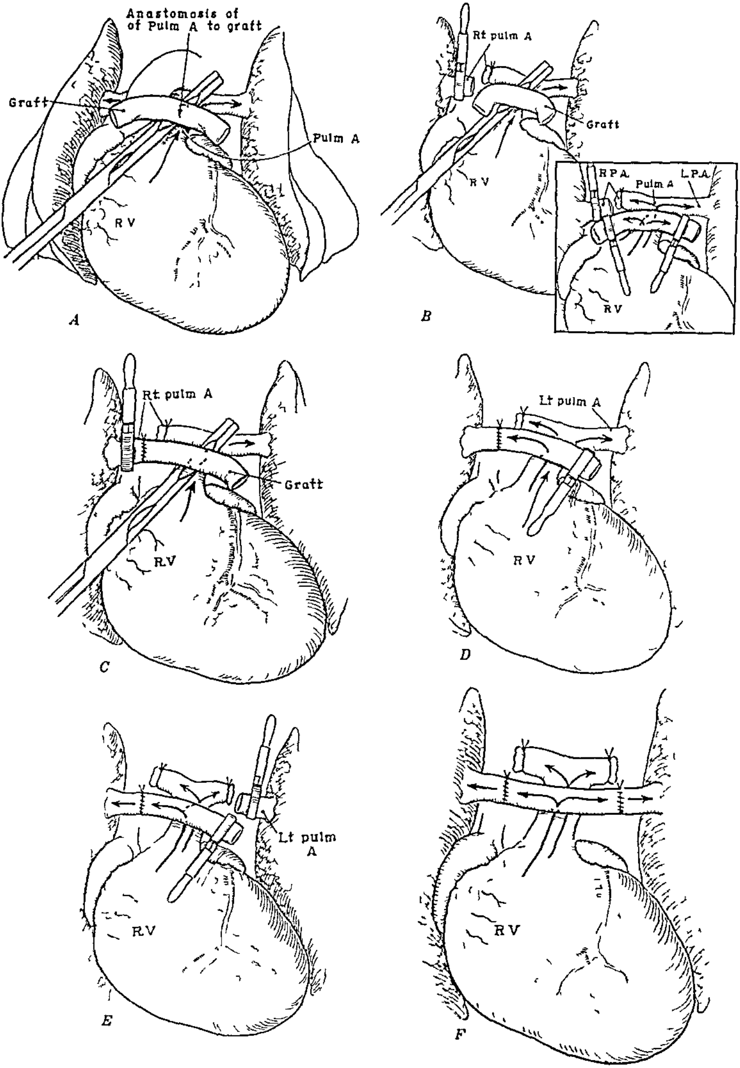

Fig 2.—Diagrams of Method 2 for replacement of pulmonary artery Cardiopulmonary bypass is not employed (see text)

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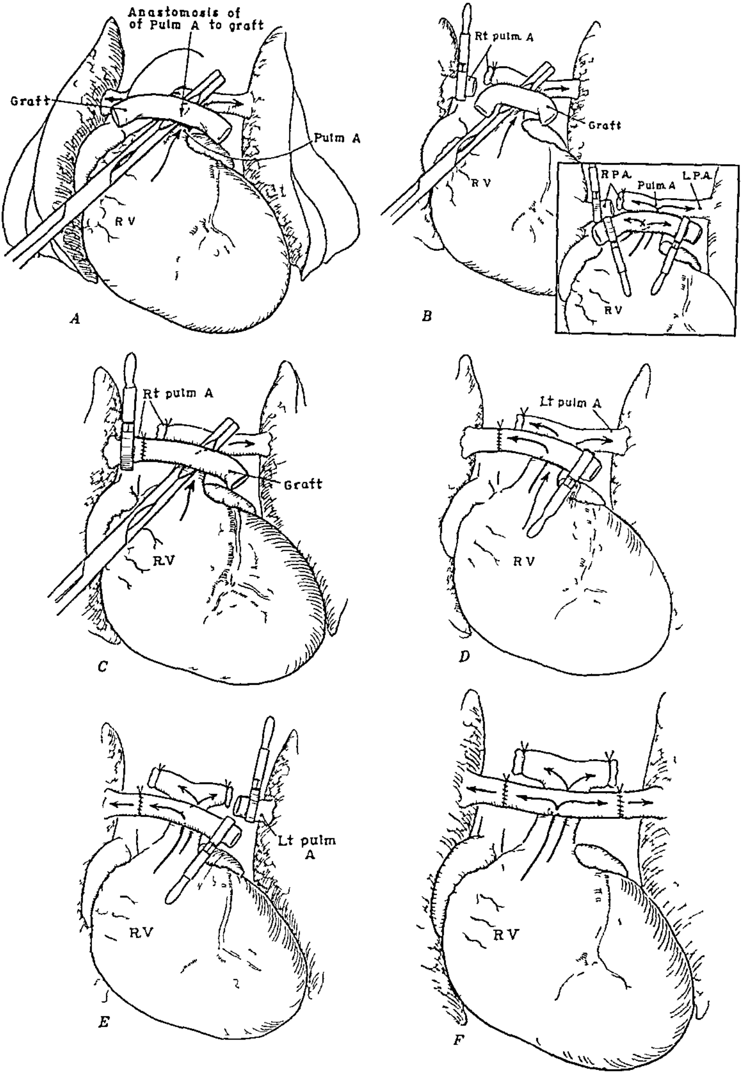

Fig. 2.—Diagrams of Method 2 for replacement of pulmonary artery. Cardiopulmonary bypass is not employed (see text).

there was degeneration of the graft with associated hemorrhage. Both of these cases were associated with infection. Causes for death could not be ascertained in 2 cases and in these the grafts appeared to be normal and healthy.

Three dogs died after diagnostic procedures such as cardiac catheterization and angiocardiography, at 70, 133, and 150 days. The cardiac catheterization performed on the 70-day survivor revealed no hypertension in the right heart, and no gradient in pressure between the right ventricle and pulmonary arteries distal to the bilateral graft. Examination of this specimen showed irregular rigidity of the graft with gross evidence of early calcification of the wall. There was no ulceration of the graft, which was smoothly lined with endothelium except for one small area in the right limb of the graft, where there was a loosely attached ante-mortem thrombus. The three anastomoses were smooth and patent

Fig. 3.—Angiocardiogram 5 months postoperatively, in anteroposterior and left lateral projections, showing patent graft, residual pouch of main pulmonary artery, and normal pulmonary vasculature (Method 2)

The peripheral pulmonar revealed a small nonocclusive thrombus
in a peripheral artery lobe. The supravalvular segment of
the mail pulmonary ar sis.
Angiocardiograp dogs surviving 133 and 150 days.
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graft (Fig. 3). Three days later the animal died of pneumonia. Post mortem examination revealed extensive calcification of the graft and ulceration of the intima, up to the suture lines. The graft was completely rigid and broke under pressure like an egg shell. The heart was normal in appearance and the supravalvular segment and blind pouch of the main pulmonary artery were free of thrombi. Other dogs are being maintained for long-term observations.

Microscopic examination was made of 6 grafts, in place for 4, 5, 22, 31, 133 and 150 days, respectively. Detailed studies of these and of the grafts still functioning will be reported subsequently.[4] In the 2 grafts in place for over 4 months, there were extensive degenerative changes in the media, including actual calcification. The cellular architecture of the grafts was completely replaced by fibrous tissue, with organized mural thrombus of varying thickness covered by a layer of endothelial cells.

DISCUSSION

The feasibility of replacing the pulmonary artery has been demonstrated by these experiments, the principal problem now is the selection of an appropriate material. Observations made on three aortic homografts in place for 70, 133 and 150 days showed gross and microscopic evidence of degeneration. It should be pointed out that none of these dogs died as a result of the grafts; however, in each instance, a diagnostic procedure such as cardiac catheterization, angiocardiography, or both, preceded death in what otherwise appeared to be healthy postoperative animals. Further observation will be necessary to determine conclusively the suitability of aortic homografts for long term replacement of pulmonary arteries. The preliminary observations strongly suggest that aortic homografts are as unsatisfactory here as they are in other low pressure (venous) systems. Synthetic prostheses of woven fabric are now being tried under the same experimental conditions.

Experience with the pump oxygenator was discouraging from the viewpoint of survival. This technique would be necessary only in clinical situations where the immediate supravalvular portion of the pulmonary artery was unsuited for placement of a side to side anastomosis. In the study of the pathologic features of chronic thrombosis of the pulmonary artery all but one case reported had a supravalvular zone free of thrombus,[7] and presumably there was a satisfactory free length for placement of the graft.

The clinical situations for which pulmonary artery replacement may have application include (1) chronic thrombosis of the pulmonary artery, (2) coarctation of the pulmonary artery, (3) atresia of the pulmonary artery, (4) aneurysms of the pulmonary artery, (5) tumors involving the pulmonary artery, and (6) trauma to the pulmonary artery.

SUMMARY

1. Two techniques for replacement of the main pulmonary artery and its bifurcation are presented. The first method employs the extracorporeal pump oxygenator and permits the supravalvular portion of the main pulmonary

to be anastomosed to the graft in end-to-side fashion. The second technique obviates the need for cardiopulmonary bypass by fashioning the proximal anastomosis in side-to-side fashion.

2. Examination of seven aortic homografts after relatively short periods in situ revealed patent grafts in all instances. These showed progressive states of degeneration and tentatively indicate that aortic homografts are unsuited for placement in the pulmonary artery of the dog.

3. Some of the clinical applications for pulmonary artery replacement are enumerated.

4. Further study of the problem is in progress employing other grafting materials.

We are grateful to Mr. Ruthven Ferreira and Mr. Alphonso Henry for invaluable technical assistance throughout this investigation.

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(For Discussion, see page 615)

EXPERIMENTAL RESULTS WITH A PROSTHETIC AORTIC VALVE

Benson B Roe, M D , John W Owsley, M D (by invitation), and Peter C Boudoures, M D (by invitation) San Francisco, Calif

THE IRREVERSIBLY destructive nature of certain types of acquired valvular heart disease precludes the restoration of satisfactory function by ordinary surgical maneuvers Resection of the abnormal anatomic valve and substituting in its place a suitable prosthetic device is the apparent solution to the problems of aortic and mitral regurgitation and calcific aortic stenosis

Such a prosthesis must comply with certain specifications if it is to be acceptable for use in human patients To be effective, a valve should be mechanically efficient, providing minimal resistance to forward flow and effective prevention of regurgitant flow, preferably without crushing action It should be designed to afford safe and reliable fixation but so as not to impede the function of other valves, not to occlude the coronary ostia nor to disturb normal fluid dynamics The valve should be composed of a material that is nontoxic noncarcinogenic and which precludes the erosion of tissues and superficial clotting In addition, the material should be able to maintain its tensile strength indefinitely within the blood stream

Four years of laboratory and engineering experience with various designs and materials have led to the development of a successful method of production and implantation of a mechanically satisfactory valve which seems to satisfy most of the requirements outlined The design of the valve, the characteristics of the material now in use, and the method of manufacture have been described elsewhere (Fig 1) [1]

The prosthesis is made of a monomolecular silicone and is cast under pressure in a precision die The three cone shaped, thin, flexible cusps of the valve retract readily and produce minimal resistance to systolic flow (5 to 10 mm Hg) The valve is totally competent in the closed position and resists static pressures of more than 500 mm Hg before tearing and prolapsing The action of the valve has been studied in a pulse duplicator under wide ranges of flow and back pressure to verify its competence and the retraction of its cusps There appears to be little turbulence, either at the

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From the Surgical Research Laboratories of the University of California School of Medicine, San Francisco Calif

Supported by the Christine Breon Fund for Medical Research and the San Franc Sacramento Heart Associations

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(For Discussion, see page 615)

edges of the prosthesis or behind the valvular cusps, although the animals in whom the earlier models were used developed thrombi behind the leading edge of the prosthesis, presumably from intermittent eddy flow (Fig. 2). Later models have more rigid and tightly fitting ends with flanges to act as gaskets (Fig. 3). Fixation by suture through the aortic wall into the ring of the prosthesis has been satisfactory, although in two earlier defective valves the sutures tore out and the valves migrated.

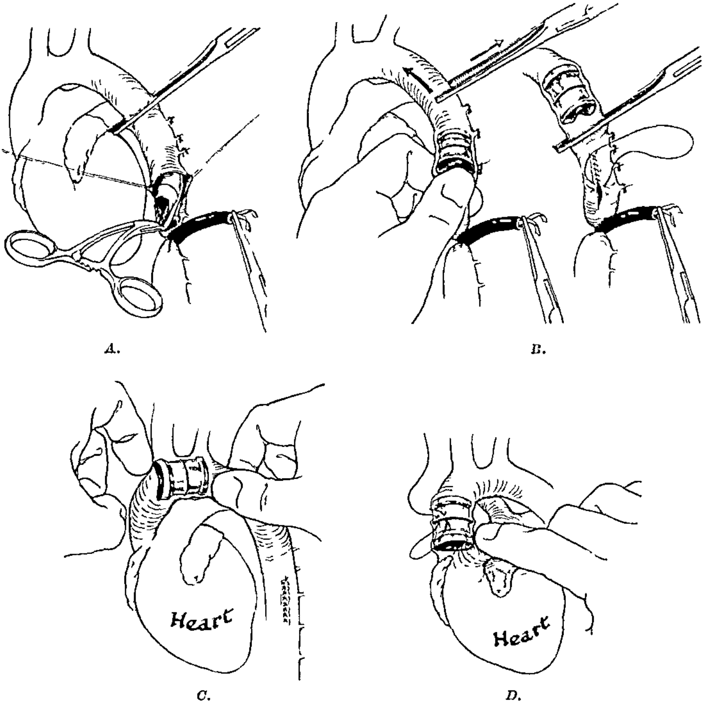


Fig. 4.—Technique for insertion of prosthetic flexible aortic valve. *A*, Insertion of folded prosthesis through distal aortotomy. Intercostal branches are occluded with dura clips.

B, Proximal clamp is released as prosthesis is extruded upward; bleeding is controlled by thumb pressure. The clamp is reapplied and aortotomy is sutured.

C, Prosthesis is pushed across the aortic arch. Finger pressure at brachiocephalic take-off starts downward course at leading edge.

D, Valve in proper position is sutured through the aortic wall into the fixation ring.

When properly cast and flamed, the silicone material has a smooth, nonwettable surface which effectively prevents clotting. No thrombi have been found in the valvular cusps or inner surfaces of prostheses that have been in place for periods up to 1 year. The flexibility and strength of these valves

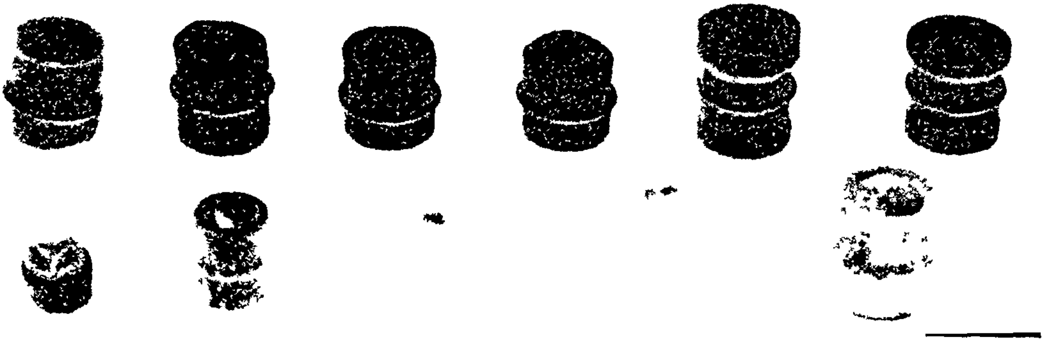


Fig. 1 —Successive models of cast, flexible valve prostheses At the left of the front row are shown in first two models, made of compressed Ivalon. The other three models in the front row are made from polyvinyl chloride In the back row are silicone valves; the changes in the cusp contour and end design were made to obtain improved fitting and prevent the formation of clots

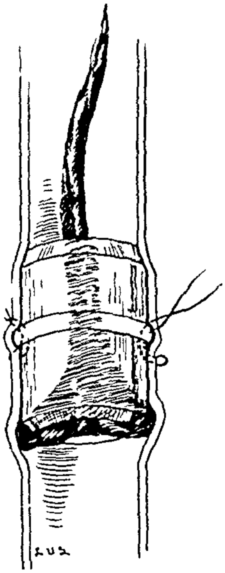


Fig. 2.—The diagram demonstrates an earlier model with tapered ends Clot formation occurs outside the prosthesis and propagates into the stream through the valve

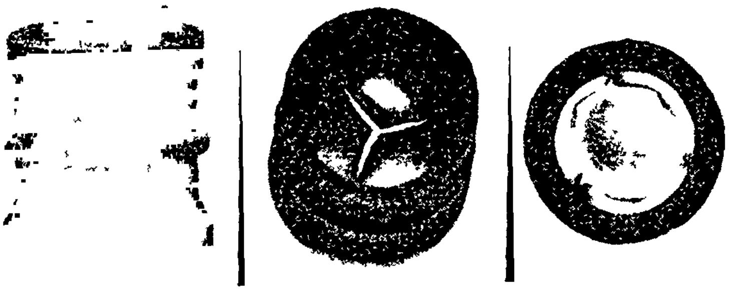


Fig 3.—Three views of a current model valve. The flanged ends act as gaskets to prevent currents between the prosthesis and aortic wall

The surgical results of implantation of this prosthesis in the experimental animal are more encouraging than the mortality rate would indicate (Table I). Technical problems were worked out in a previous series of 40 dogs with Ivalon and polyvinyl valves. Operative deaths frequently occurred in the current series because of problems arising from improper fitting. Until now only one size of valve has been available and it is not possible to select accurately animals with desirable sized aortas; in the interests of time and to gain experience we inserted many valves which were manifestly too large or too small. While the hazards with a properly sized valve are less than those with an ill-fitting valve, they are nevertheless similar in kind. Experience with this handicap resulted in reducing and correcting such disastrous mishaps as turning or inverting the prosthesis in transit across the aortic arch, tearing the delicate proximal aorta while placing the anchoring sutures, losing the prosthesis in the ventricle, and incorrectly placing the prosthesis so that it occluded the coronary ostia. Early postoperative deaths were

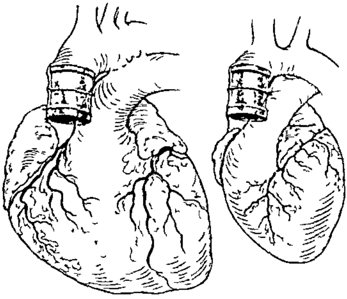


Fig. 6.—The human ascending aorta (*left*) is longer relative to its diameter than that of the dog (*right*). Note that the distal end of the valve in the dog extends into the arch.

TABLE I. TOTAL EXPERIENCE WITH SILICONE AORTIC VALVES

Operative Deaths		19
Internal version*	7	
Malposition*	5	
Hemorrhage*	5	
Poor fit*	2	
Brief Survivors (2-10 Days)		16
Hemorrhage* (including 2 with dislocation of prosthesis)	4	
Empyema	3	
Embolism	5	
Miscellaneous unrelated	4	
Long Term Survivors (14 Days-6 Months)		9
Thromboembolism	4	
Hemorrhage	1	
Empyema	1	
Unrelated	3	
Living (3-12 Months) (2 sacrificed at 8 mo.)		7
Total		51

*Ill-fitting valves.

seem to be unaltered after implantation; however, one imperfect model, after being in a dog for 8 months, was subjected to stress on the pulse duplicator for 780 hours at 150 beats per minute with diastolic gradients exceeding 300 mm. Hg, after which a defect developed in the center of a cusp. The newer model valves are more perfectly molded and their material strength has been increased.

Since the hygroscopic property of the material may be an index of its loss of elasticity and fatigue, the prosthetic valves were weighed to determine the extent of water uptake. Valves implanted for periods of 3 weeks to 3½ months showed a gain in weight of 0.4 per cent to 1.9 per cent. These levels are considered to be safely below the critical absorption level of 3 per cent.[2]

No information is yet available on the carcinogenic properties of silicone compounds, but Bering and co-workers[3, 4] have pointed out this danger with various plastic compounds and such a potential hazard must be kept in mind.

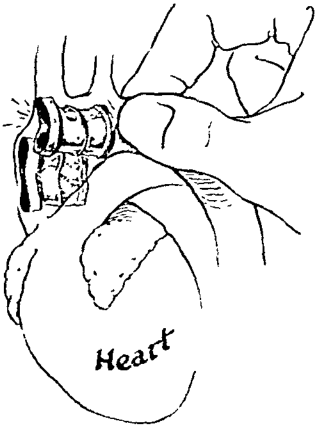


Fig. 5.—Failure to direct the leading edge causes valve to catch in the brachiocephalic orifice. Further descent takes place in the transverse position.

The previously described technique[5] of placing the valve in the ascending aorta above the coronary ostia has been simplified to avoid inserting a loop of heavy suture through the proximal aortic wall. The folded prosthesis is inserted into the occluded descending thoracic aorta and is manually pushed in a retrograde direction over the aortic arch and downward into the ascending aorta; here it unfolds and the palpable valvular action begins (Fig. 4). By use of posterior pressure the finger places the leading edge of the valve above the coronary ostia and the distal edge proximal to the curvature of the arch (Fig. 5).

In order that correct alignment be maintained, the axial length of the prosthetic cylinder should be greater than its diameter. This length presents a problem in the dog, whose ascending aorta is usually less than two diameters long. Occasionally there is not sufficient distance below the curvature of the arch and above the coronary vessels to contain the prosthetic cylinder. The human ascending aorta, however, appears to be relatively longer which should make the accuracy of placement less critical (Fig. 6).

The surgical results of implantation of this prosthesis in the experimental animal are more encouraging than the mortality rate would indicate (Table I). Technical problems were worked out in a previous series of 40 dogs with Ivalon and polyvinyl valves. Operative deaths frequently occurred in the current series because of problems arising from improper fitting. Until now only one size of valve has been available and it is not possible to select accurately animals with desirable sized aortas; in the interests of time and to gain experience we inserted many valves which were manifestly too large or too small. While the hazards with a properly sized valve are less than those with an ill-fitting valve, they are nevertheless similar in kind. Experience with this handicap resulted in reducing and correcting such disastrous mishaps as turning or inverting the prosthesis in transit across the aortic arch, tearing the delicate proximal aorta while placing the anchoring sutures, losing the prosthesis in the ventricle, and incorrectly placing the prosthesis so that it occluded the coronary ostia. Early postoperative deaths were

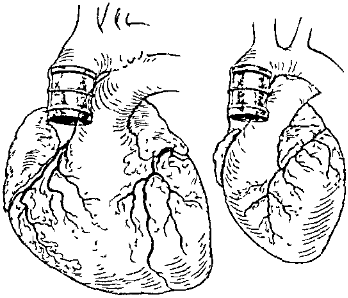


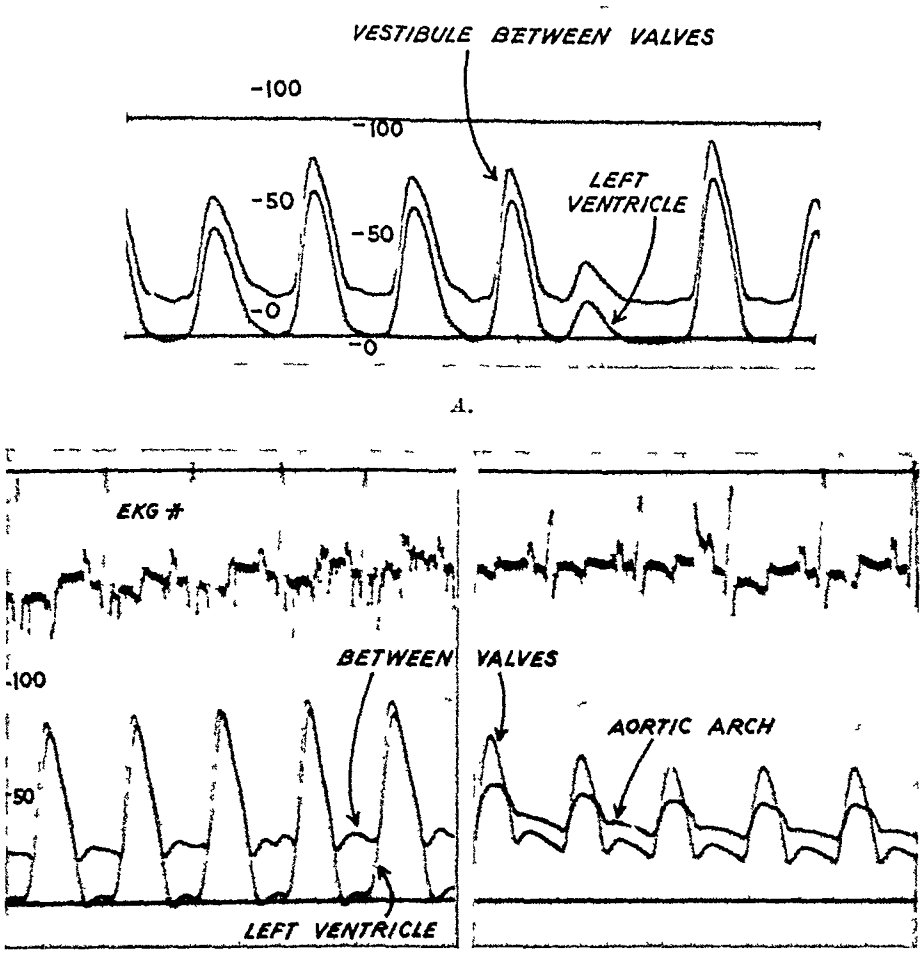
Fig 6.—The human ascending aorta (*left*) is longer relative to its diameter than that of the dog (*right*). Note that the distal end of the valve in the dog extends into the arch.

TABLE I. TOTAL EXPERIENCE WITH SILICONE AORTIC VALVES

Operative Deaths		19
Internal version*	7	
Malposition*	5	
Hemorrhage*	5	
Poor fit*	2	
Brief Survivors (2-10 Days)		16
Hemorrhage* (including 2 with dislocation of prosthesis)	4	
Empyema	3	
Embolism	5	
Miscellaneous unrelated	4	
Long-Term Survivors (14 Days-6 Months)		9
Thromboembolism	4	
Hemorrhage	1	
Empyema	1	
Unrelated	3	
Living (3-12 Months) (2 sacrificed at 8 mo.)		7
Total		51

*Ill-fitting valves.

caused by hemorrhage, formation of clots around the valve, or partial obstruction of the coronary arteries. Of significance, however, is the immediate survival of 30 dogs, which indicates the physiologic tolerance to a competent valve distal to the coronary arteries, and the longer survival of 15 dogs.



A.

B.

Fig 7.—*A*, Dog. No 234. Pressure curves after implantation of prosthetic valve, anatomic valve intact. Upper curve is from ascending aorta proximal to the prosthesis (note different zero levels). The similarity to the left ventricular curve (lower) suggests that the anatomic valve is not closing and coronary arteries must be filling in systole.

B, Dog. No. 26 Left ventricle and aorta between valves Diastolic pressure above anatomic valve indicates competence of this value and probable diastolic filling of coronary arteries In the right portion of the pressure curve the aorta between valves and aortic arch distal to the prosthesis is shown Note the systolic gradient across the prosthesis and diastolic gradient indicating competence.

The clinical possibilities of this device thus appear to be promising inasmuch as it is well tolerated, remains flexible and functioning, and prevents surface clotting. Its physiologic value in a position distal to the coronary arteries remains unsettled, however, since our results have been obtained with the anatomic valve intact about 1.5 cm. proximal to the prosthesis Study of the left ventricular outflow tract reveals that its configuration and its proximity to the mitral valve offers significant problems of positioning and fixation which we did not wish to introduce in the preliminary evaluation of the device and modifications of the valve are being made for subcoronary placement with bypass techniques.

The possibility that coronary artery filling would take place during systole and would be sufficient to sustain myocardial function is worthy of further consideration. If a prosthetic valve is tolerated in the ascending aorta its placement would be considerably safer and simpler.

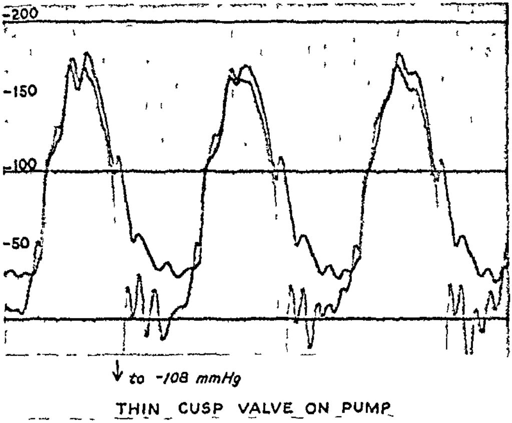


Fig 7 (Cont'd).—C. Pressure curves in pulse duplicator above and below prosthetic valve. Diastolic gradient is 138 mm and systolic gradient is 10 mm

Pressure studies done after introduction of our prosthesis indicate that the small space proximal to the new valve and distal to the anatomic valve does maintain a small diastolic pressure (Fig. 7) which may be sufficient to maintain coronary flow. Attempts at transventricular avulsion of the anatomic cusps at the time of implantation of the prosthesis uniformly led to irreversible ventricular fibrillation. In 2 dogs, avulsion of the anatomic cusps was carried out several months after implantation; 1 dog survived for 24 hours and another for 4 days, each apparently dying from embolic phenomena arising underneath the prosthesis.

SUMMARY

A flexible tricuspid prosthetic valve has been developed and implanted in the ascending aorta of a series of laboratory animals. This device has low resistance, is totally competent, and is made of silicone rubber which appears to have properties of clot prevention and which maintains its elasticity in the blood stream. This valve has been implanted in the ascending aorta, above the functioning anatomic valve, where it appears to be physiologically tolerated and hemodynamically effective.

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(For Discussion, see page 615)

POSTMORTEM STUDY OF THE TECHNIQUE OF AORTIC VALVULOTOMY IN CALCIFIC AORTIC STENOSIS BY QUANTITATIVE EXAMINATION OF VALVULAR FUNCTION BY PERFUSION

W Gerald Austen, M D (by invitation) Robert S Shaw, M D , J Gordon Scannell, M D , and W M Thurlbeck M D (by invitation), Boston, Mass

THE FIRST attempt to correct aortic stenosis by operation is credited to Tuffier[1] who, in 1913, endeavored to dilate an aortic valve blindly through the aortic wall In 1946, Smithy[2] and his associates reported their experimental work in dogs involving both transventricular and transaortic incision of the aortic valve By 1950, Bailey was ready to recommend a transventricular closed approach[3] in patients, and later a transaortic approach[4] Brock[5] and others[6] have reported similar experience More recently, open operation with valvulotomy under direct vision has been advocated, using hypothermia[7] and cardiac bypass[8] Objective evaluation of the degree of improvement accomplished by these reported procedures is rarely available High operative mortality, embolic phenomena, inconsistent relief of stenosis, and the production of significant degree of aortic regurgitation have all been encountered

Against this background, the following study of postmortem specimens was undertaken to determine, *by objective measurements,* whether significant improvement in valvular function could indeed be accomplished by surgery in acquired calcific aortic stenosis, and particularly to determine whether stenosis could be relieved adequately without the production of major degrees of aortic regurgitation

MATERIAL AND METHODS

Quantitative techniques of evaluating valvular function in the heart at autopsy by perfusion have been described in a previous publication[9] The apparatus used is shown in Fig 1 This apparatus allows the perfusion of a valve in either direction at a variable rate of flow and provides measurement of the pressure gradient across the valve, the rate of flow, and the temperature of the perfusate Steady rather than pulsatile flow is used because

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(For Discussion, see page 615)

correlates the degree of stenosis as indicated by the slope of the curve obtained on postmortem perfusion with the ante mortem clinical severity of the aortic stenosis.

To study aortic regurgitation the flow was reversed and the valve perfused from aorta to left ventricle. A normal aortic valve closes promptly and allows no flow with pressures up to several hundred centimeters of water, giving a vertical curve of infinite slope. The more regurgitant the valve,

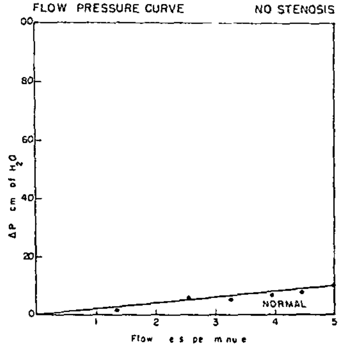

Fig. 2.—Flow pressure relationship for forward flow in a normal aortic valve.

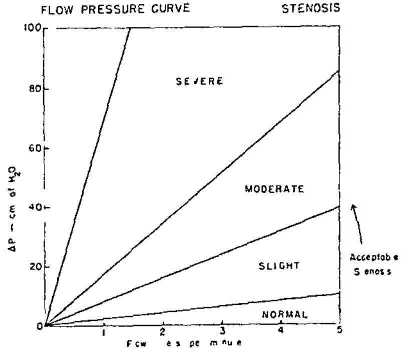

Fig. 3.—Summary of forward flow pressure curves correlating the degree of stenosis as indicated by the slope of the curve obtained on postmortem perfusion with the ante mortem clinical severity of the aortic regurgitation.

the greater the flow through the valve, and the less the pressure differences across the valve at any particular rate of flow. Fig. 4 shows the range of slopes for normal, slight, moderate, and severe clinical degrees of aortic regurgitation. The areas labeled "normal" and "slight" in Figs. 3 and 4 the resulting data are interpreted more easily in hydraulic terms. Unpublished work at this laboratory has shown that, in the pressure flow relationship through a stenotic valve, there is no significant difference between blood and water used as the perfusate. In this study, therefore, water was used to perfuse the valves.

The degree of aortic stenosis was determined by perfusing the aortic valve from left ventricle to aorta, and plotting the observed pressure drop across the valve against the rate of flow. While the theoretical curve thus obtained would describe an exponential function, for the purpose of this experiment it was assumed to be linear and the slope of the curve obtained by drawing the most appropriate straight line through several observed points. Fig. 2 shows a typical plot of the pressure flow relationship in a normal aortic valve. The more stenotic the valve, the greater the pressure drop across the valve at any particular flow and the greater the slope of the curve obtained. Fig. 3 summarizes unpublished observations at this laboratory and

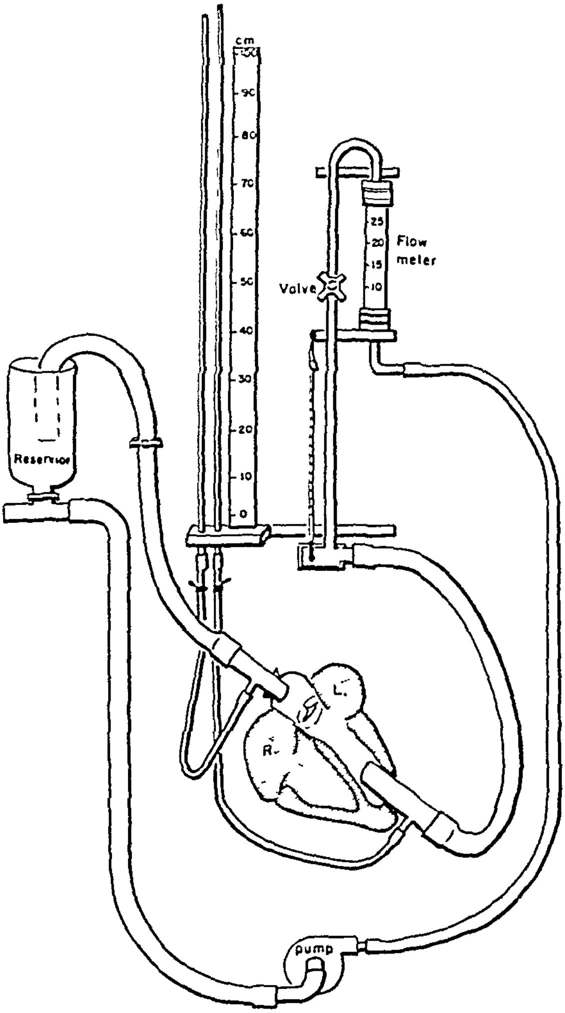

Fig. 1.—Perfusion apparatus.

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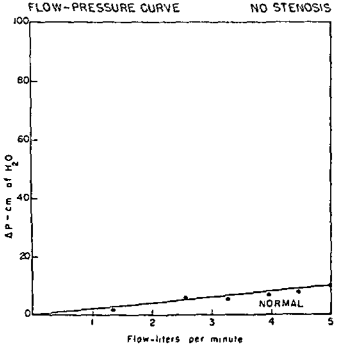
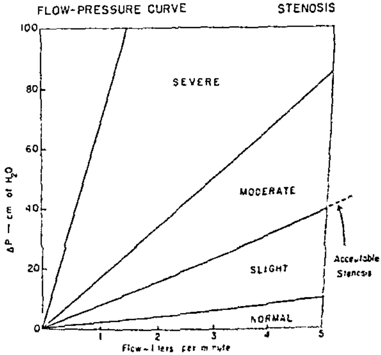


Fig. 2.—Flow-pressure relationship for forward flow in a normal aortic valve.



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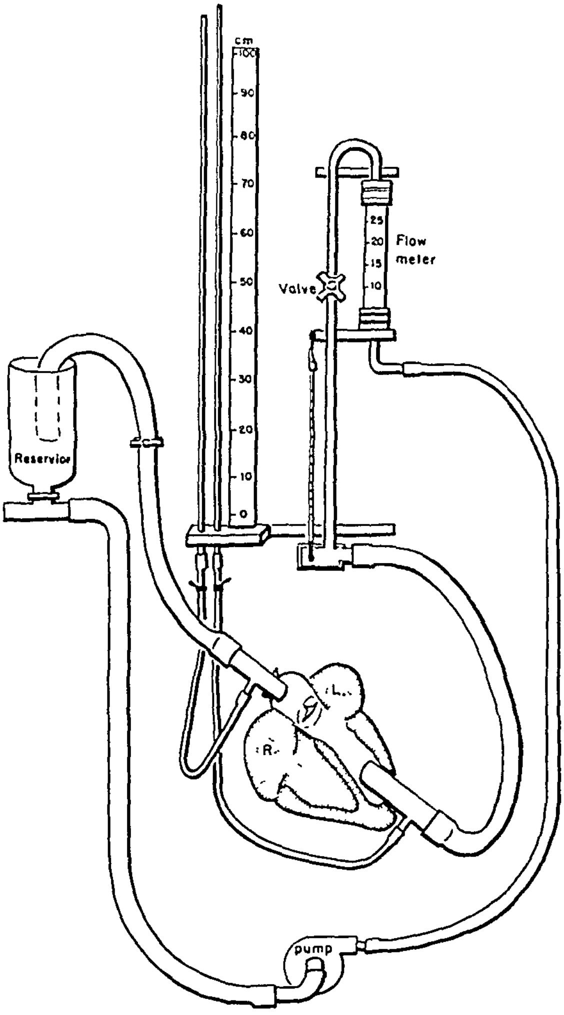


Fig. 1.—Perfusion apparatus.

the valves were not separated exactly along their line of fusion, and severe regurgitation and embolization resulted. This accident was avoided with further experience. We found that familiarity with the gross pathology allowed an accurate commissurotomy to be performed in even the most impossible looking valve

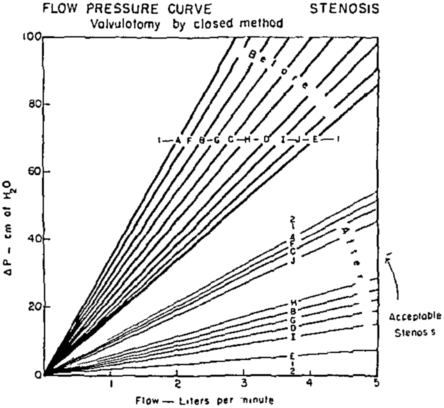


Fig 5 —Flow-pressure curves for valvulotomy by the closed method, which show stenosis incompletely relieved in 4 (A, C, F, and J) out of 10 cases

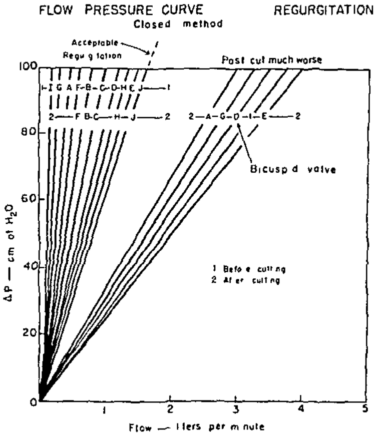


Fig 6 —Flow-pressure curves for valvulotomy by the closed method which show the resultant severe regurgitation in 5 (A, D, E, G, and I) of 10 cases

In order to attain an accurate commissurotomy, identification of the line of fusion of the cusps was necessary, and this was not easy in the deformed represent perfusion data of cases clinically asymptomatic during life; in the charts the valvular function that these areas represent is referred to as "acceptable."

With these background data available, hearts from 36 patients who died with aortic stenosis were studied, and then restudied after the performance of various reconstructive procedures.

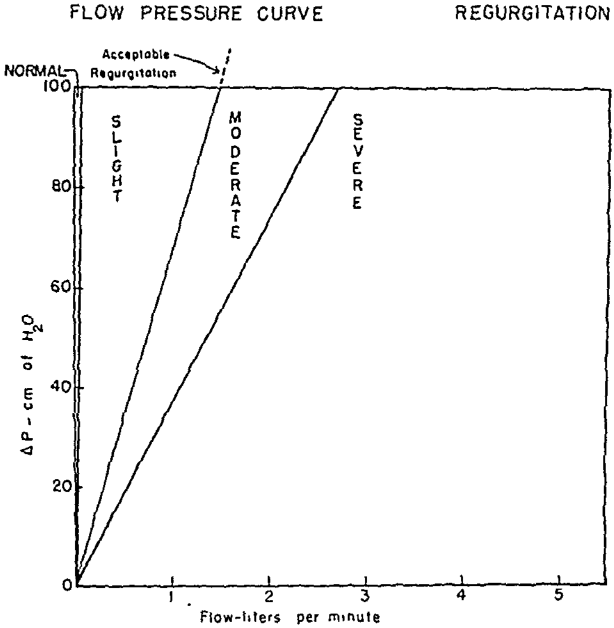


Fig. 4.—Summary of retrograde flow-pressure curves correlating the degree of regurgitation as indicated by the slope of the curve obtained on postmortem perfusion with the ante mortem clinical severity of the aortic regurgitation.

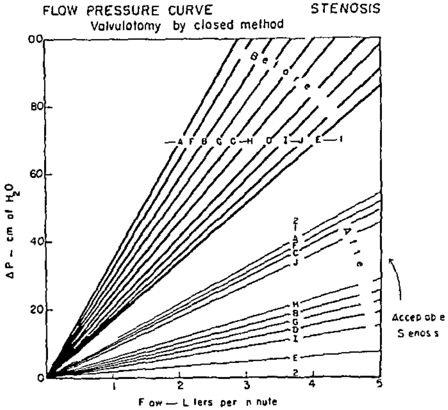
RESULTS

"Closed" Commissurotomy.—

In an initial 10 cases, valvuloplasty was attempted by blind instrumentation through the aorta. An effort was made to follow reported techniques of closed aortic valvuloplasty, including the use of mechanical dilators. One of the 10 cases was of a bicuspid valve which was not recognized and was blindly cut as if it were a tricuspid valve. As shown in Fig. 5, stenosis was adequately relieved in 6 cases and incompletely relieved in 4. The regurgitation data are shown in Fig. 6. Severe regurgitation resulted in four of the nine tricuspid valves, including one of three valves instrumented with the Bailey dilator, and in the one bicuspid valve. The remaining five valves showed essentially no change in regurgitation. These results were consistent with the anatomic findings after instrumentation, which showed frequent injury of valve leaflets and incomplete separation of their adherence. Release of gross calcific emboli into the perfusion system was observed in 4 of these 10 cases.

"Open" Commissurotomy.—

In the remaining 26 specimens the valve was approached under direct vision through an incision in the aorta. In three of the early experiments the valves were not separated exactly along their line of fusion, and severe regurgitation and embolization resulted. This accident was avoided with further experience. We found that familiarity with the gross pathology allowed an accurate commissurotomy to be performed in even the most impossible looking valve.



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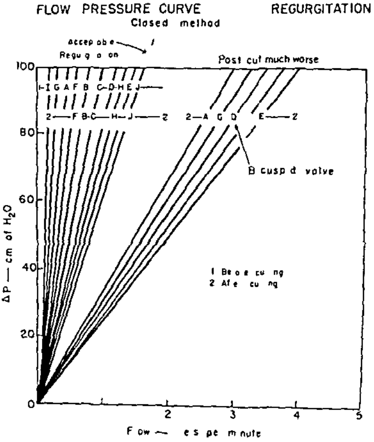


Fig. 6.—Flow pressure curves for valvulotomy by the closed method which show the resultant severe regurgitation in 5 (A, D, E, G, and I) of 10 cases.

In order to attain an accurate commissurotomy, identification of the line of fusion of the cusps was necessary, and this was not easy in the deformed and calcified valve. In this regard, the following procedure was found to be most successful. The location of the original anatomic commissures at the aortic wall was first sought. At least one commissure was usually apparent, and the others sought 120 degrees away from this site. Three helpful anatomic guides used in locating these aortic attachments are shown in the simplified diagrammatic sketch (Fig. 7). (1) The anatomic points of attachment are the most distal points of valve attachment to the aortic wall. (2) They are usually marked by ridges approximately 2 mm. long, running distally along the aorta and representing an extension of the valve edges. (3) The lines of fusion of the leaflet edges are usually apparent as lumps adjacent to the aortic wall. These distal points, ridges, and lumps are shown in the photograph of an actual specimen (Fig. 8).

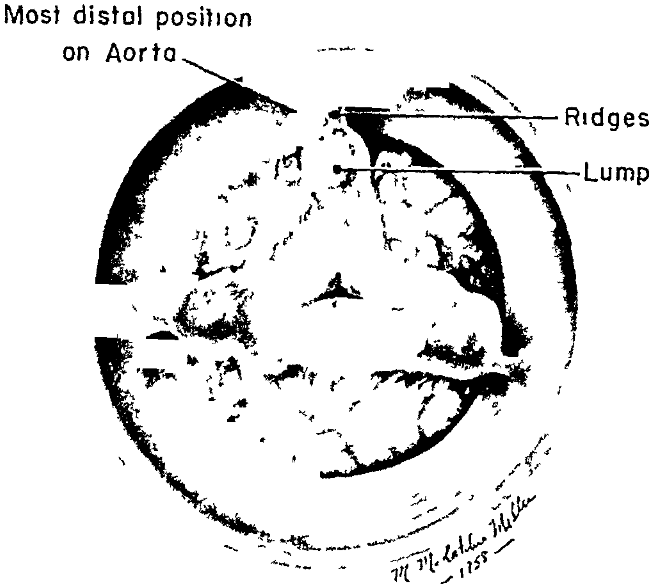


Fig 7.—Simplified diagrammatic sketch of a post-rheumatic calcified stenotic aortic valve showing important anatomic landmarks which are helpful in performing commissurotomy.

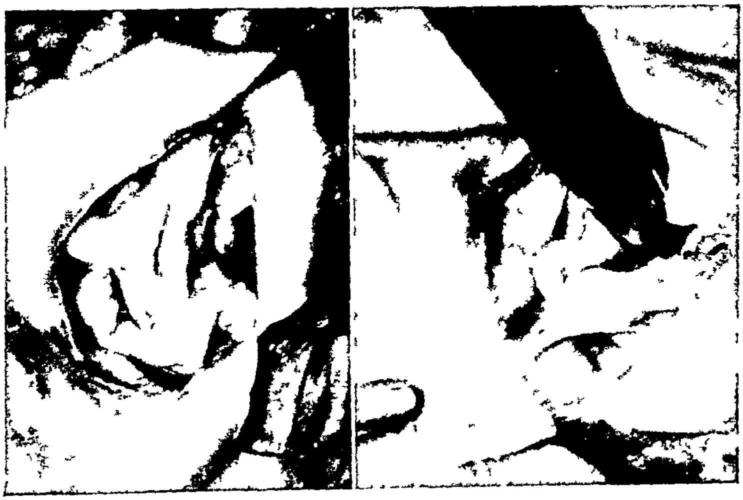


Fig. 8.—A post-rheumatic calcified stenotic aortic valve showing the anatomic landmarks

Some débridement of gross calcific deposits was frequently necessary for initial orientation. After the site of the original commissure had been defined, the fused leaflet edges were visualized by gingerly removing obscuring calcific debris. Debridement was confined to the commissural regions, since disastrous fenestration of the valve leaflet may result from debridement in the body of the leaflet. With the anatomic landmarks identified, the lines of fusion of the leaflets were cut. In some of the specimens, there was overlapping of the leaflet edges at their fusion requiring an oblique incision to avoid laceration of the leaflet edge with regurgitation as a result.

In order to test the need to divide all three commissures, in five hearts only two commissures were divided. As shown in Fig. 9, a significant degree of stenosis persisted until the third commissure was freed. Two bicuspid valves with calcific stenosis were encountered and in these specimens division of the two commissures was sufficient to relieve stenosis.

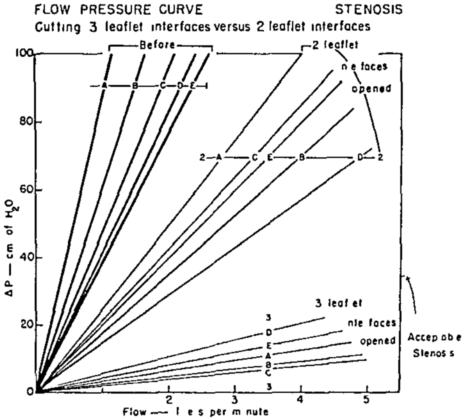
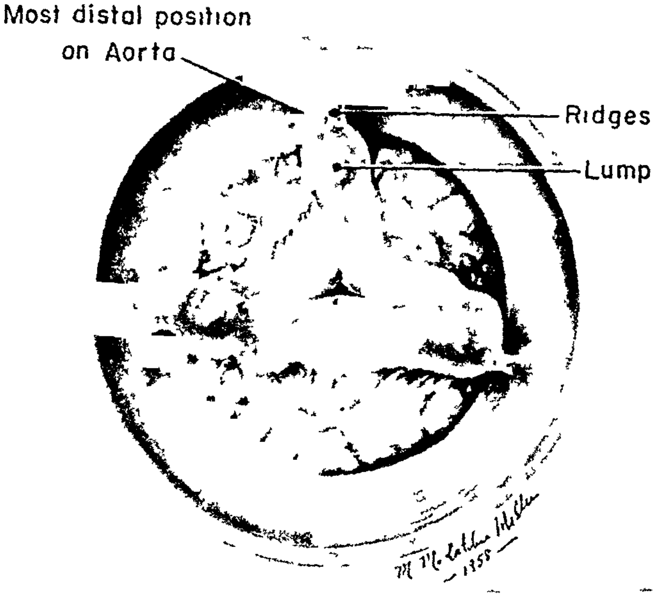


Fig. 9.—Flow pressure studies showing the need to divide all three commissures in order to obtain sufficient relief of stenosis.

In eight hearts, in order to determine the optimal extent of commissurotomy, the three commissures were cut incompletely in stages and perfused between stages, as shown in Fig. 10. Adequate relief of stenosis was not obtained until the commissures were incised to a point approximately 2 mm. from the aortic wall. Carrying the cut beyond this point and to the aortic wall accomplished no further improvement in stenosis. The regurgitation measurements shown in Fig. 11 reveal the significant fact that when the valves were cut to 2 mm. from the aortic wall there was no resultant regurgitation, but when these incisions were extended to the aortic wall 50 per cent of the valves became regurgitant. Two millimeter fusion of the leaflet edges was found frequently in aortic valves which showed no evidence of stenosis on perfusion or by clinical history. One case was of particular and calcified valve. In this regard, the following procedure was found to be most successful. The location of the original anatomic commissures at the aortic wall was first sought. At least one commissure was usually apparent, and the others sought 120 degrees away from this site. Three helpful anatomic guides used in locating these aortic attachments are shown in the simplified diagrammatic sketch (Fig. 7). (1) The anatomic points of attachment are the most distal points of valve attachment to the aortic wall. (2)



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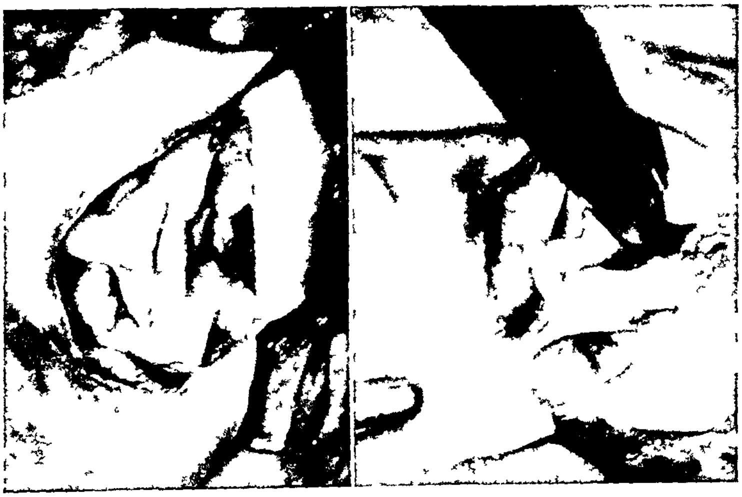

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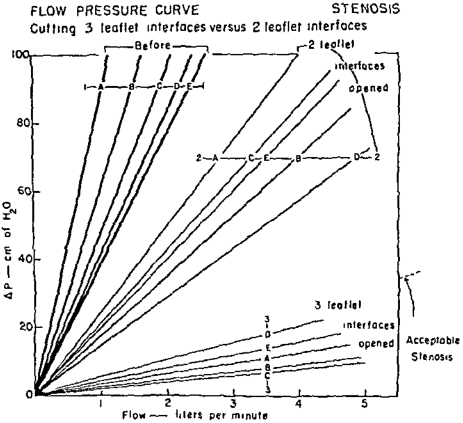

Fig. 9.—Flow-pressure studies showing the need to divide all three commissures in order to obtain sufficient relief of stenosis.

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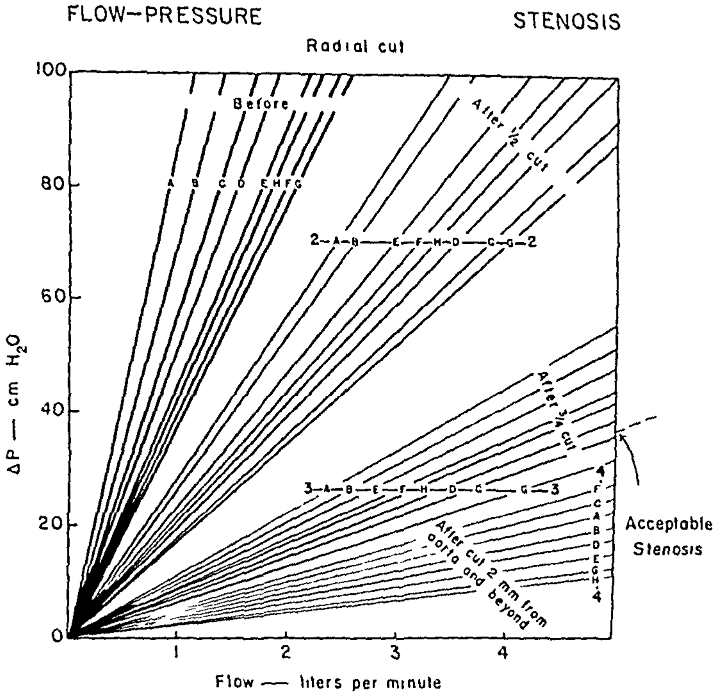


Fig. 10.—Flow-pressure studies showing that adequate relief of stenosis does not appear until the commissures are incised to 2 mm. from the aortic wall.

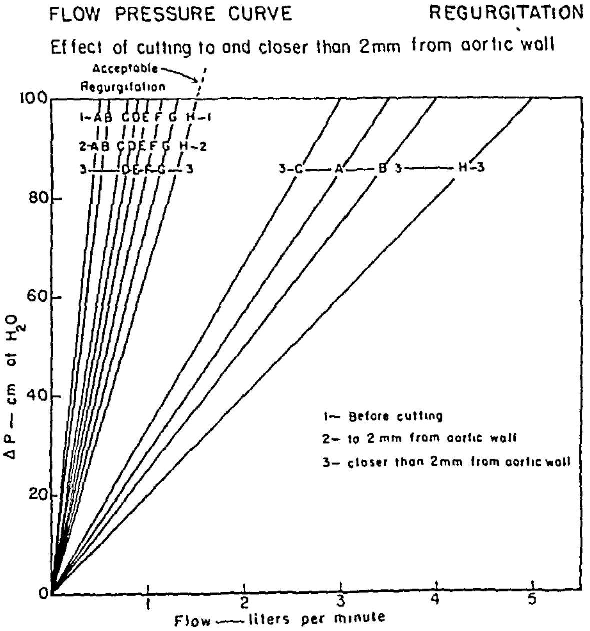


Fig. 11.—Flow-pressure studies showing the appearance of regurgitation when the valvulotomy is extended closer than 2 mm. from the aortic wall.

interest since a pathologic diagnosis of aortic stenosis had been made by the pathologist on the basis of calcification and rigidity of the leaflets. This case had at least 2 mm of commissural adhesion and looked like a stenotic valve after what we would consider adequate commissurotomy. Perfusion showed insignificant stenosis and no regurgitation, and review of the patient's record provided no clinical evidence of heart disease.

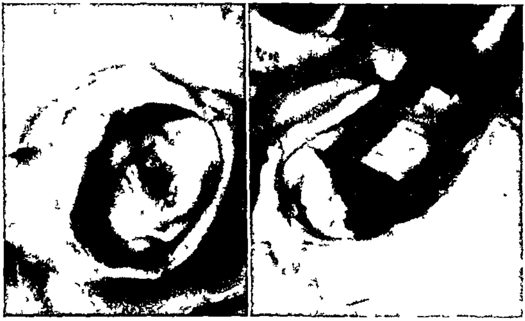


Fig 12.—A calcified stenotic post-rheumatic tricuspid aortic valve before and after open instrumentation

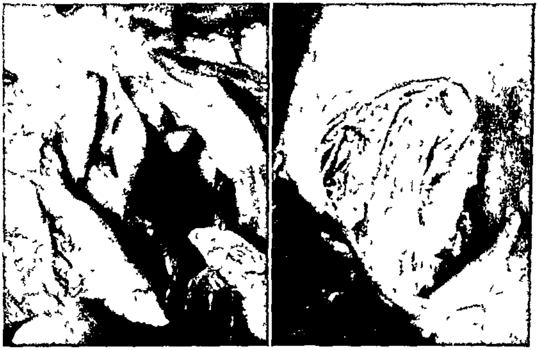


Fig 13.—A calcified stenotic post-rheumatic bicuspid aortic valve before and after open instrumentation

As a final study, ten consecutive specimens of severe calcific aortic stenosis were visualized by the transaortic approach and all three commissures were incised up to a point 2 mm. from the aortic wall in the manner previously described. Fig. 12 shows a preoperative and postoperative tricuspid aortic valve. Fig 13 shows a preoperative and postoperative bicuspid aortic valve. Pre- and post-commissurotomy perfusion data for these ten specimens are shown in Figs. 14 and 15. There was no significant residual stenosis. Regurgitation was slightly increased in only one specimen and definitely

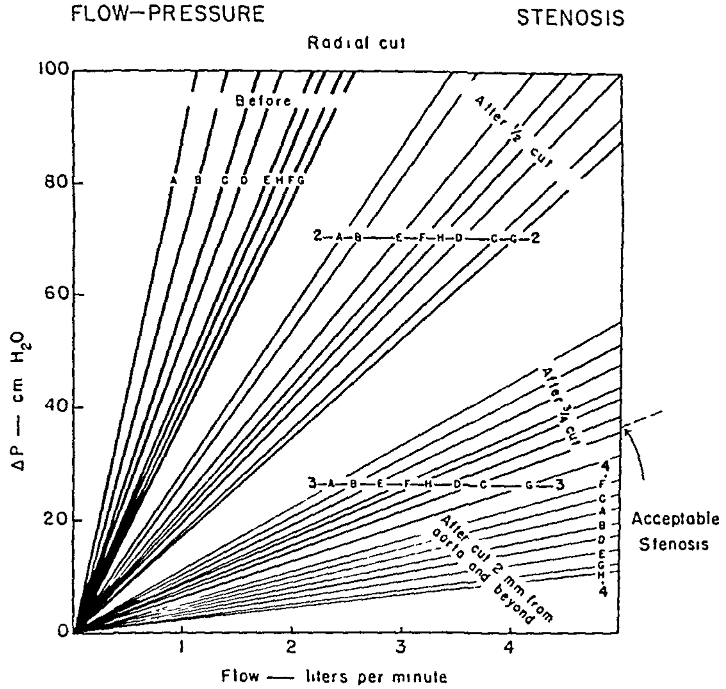


Fig. 10.—Flow-pressure studies showing that adequate relief of stenosis does not appear until the commissures are incised to 2 mm. from the aortic wall.

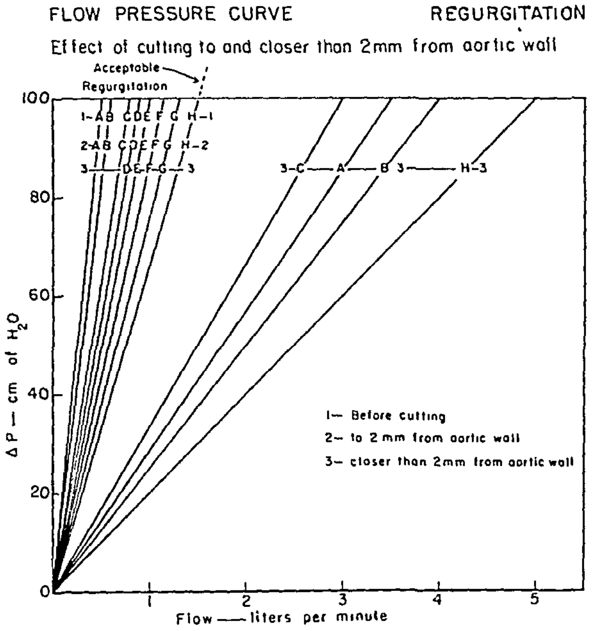
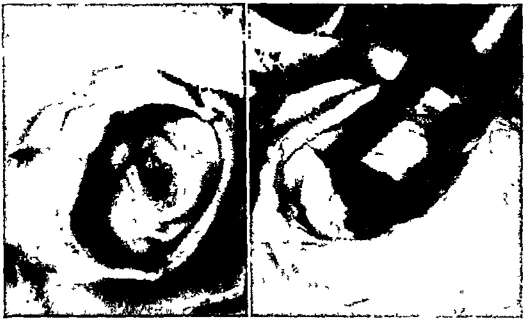


Fig. 11.—Flow-pressure studies showing the appearance of regurgitation when the valvulotomy is extended closer than 2 mm. from the aortic wall.

interest since a pathologic diagnosis of aortic stenosis had been made by the pathologist on the basis of calcification and rigidity of the leaflets. This case had at least 2 mm of commissural adhesion and looked like a stenotic valve after what we would consider adequate commissurotomy. Perfusion showed insignificant stenosis and no regurgitation, and review of the patient's record provided no clinical evidence of heart disease.



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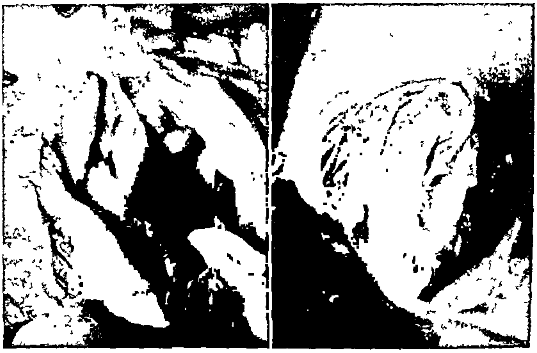

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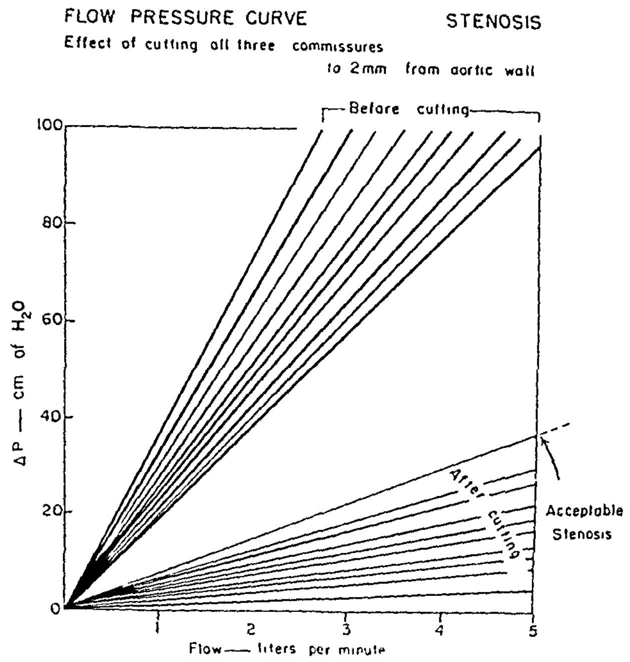


Fig. 14.

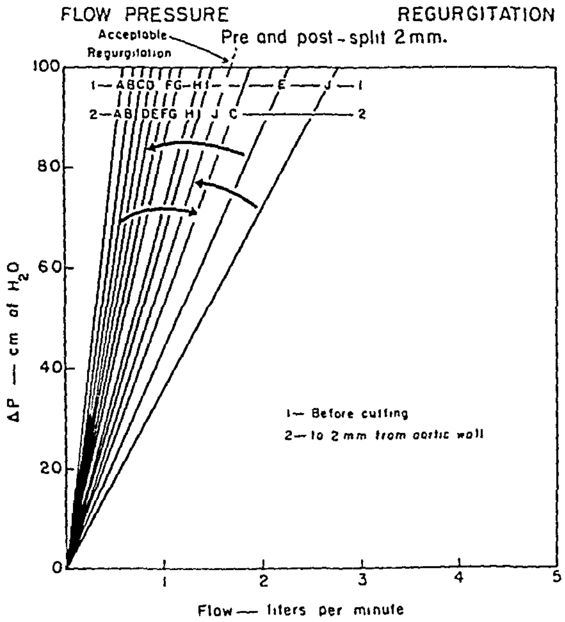


Fig. 15.

Figs. 14 and 15.—Pre- and post-instrumentation studies showing the effect on stenosis and on regurgitation in 10 consecutive autopsy cases of post-rheumatic calcific aortic stenosis where valvulotomy was performed by the open method as described.

decreased in two The improvement in regurgitation in these 2 cases did not appear until the third commissure was divided The remaining seven specimens were unchanged as regards regurgitation by commissurotomy In nine of these ten specimens, no calcium particles were released during the commissurotomy In only one of these ten specimens a few particles of calcium were released during commissurotomy but were easily removed with forceps and did not appear in the perfusing fluid

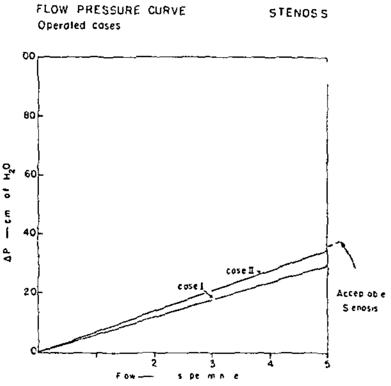


Fig 16

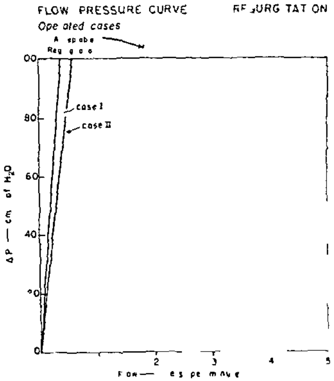


Fig 17

Figs 16 and 17—Postmortem studies on the aortic valve of 2 patients who died following transaortic open valvulotomy for severe post rheumatic calcific aortic stenosis There is adequate relief of stenosis and insignificant regurgitation

CLINICAL APPLICATION

It has been possible to apply the foregoing technical principles and methods of laboratory measurement to 2 patients in whom aortic commissurotomy was carried out by open operation but who failed to survive

The first of these was a 44 year old man with acquired aortic stenosis whose presenting symptom was angina of such intensity and severity that he was unable to tolerate left heart catheterization prior to operation Aortic valvulotomy was carried out under direct vision using a modified DeWall pump oxygenator and elective arrest with 2 5 per cent potassium citrate The valve was carefully débrided, the commissures accurately identified and incised to a point 2 mm from the aortic wall Unfortunately, it proved impossible to resuscitate this heart and the patient died Postmortem perfusion study demonstrated that only a slight and acceptable degree of stenosis persisted and that no significant regurgitation had been produced (Figs 16 and 17)

The second patient was a woman of 55 years of age with known rheumatic heart disease and aortic stenosis Her presenting complaint was syncope Preoperative left heart catheterization demonstrated a systolic pressure gradient of 125 mm Hg across the aortic valve Direct vision aor [illegible] missur [illegible]

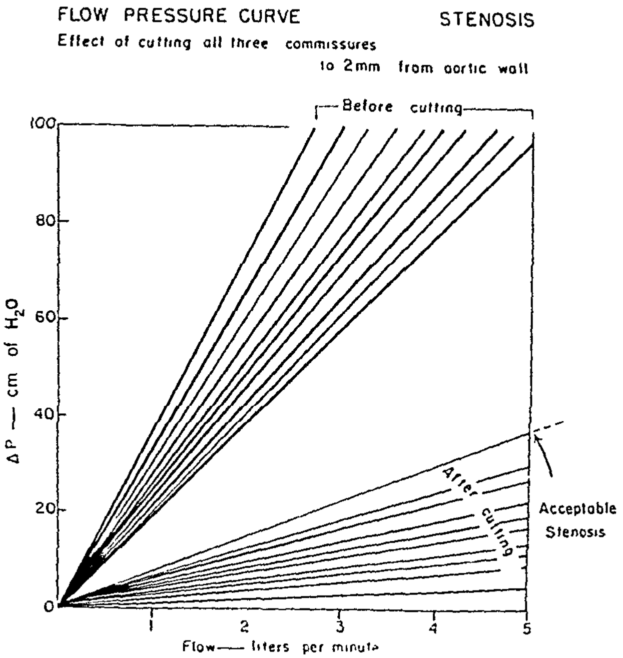
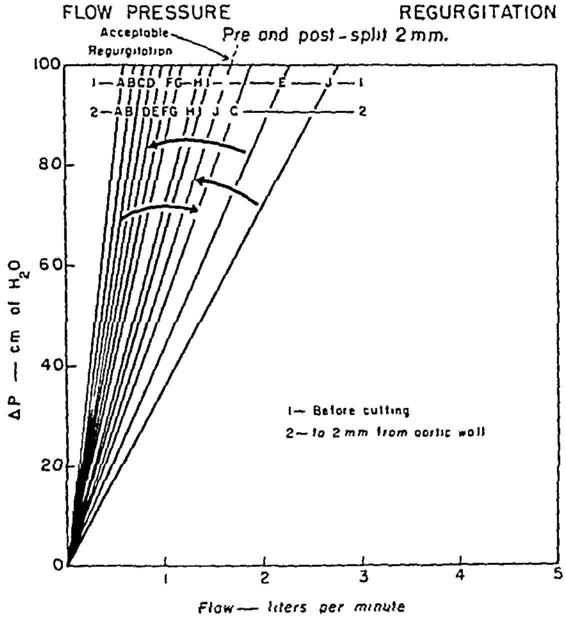


Fig. 14.



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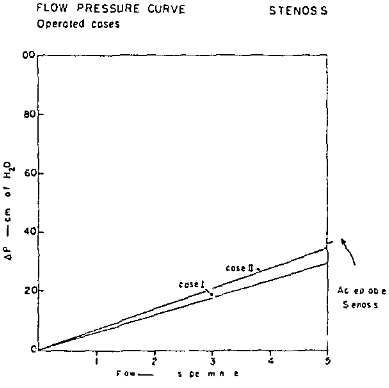
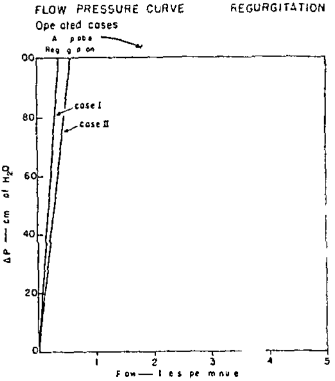


Fig 16



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Figs 16 and 17 —Postmortem studies on the aortic valve of 2 patients who died following transaortic open valvulotomy for severe post rheumatic calcific aortic stenosis There is adequate relief of stenosis and insignificant regurgitation

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The second patient was a woman of 55 years of age with known rheumatic heart disease and aortic stenosis Her presenting complaint was syncope Preoperative left heart catheterization demonstrated a systolic pressure gradient of 125 mm Hg across the aortic valve Direct vision aortic commissurotomy was carried out in the manner described above, using cardiac bypass and elective arrest. Two commissures required incision to 2 mm. from the aortic wall. After closure of the aortotomy, the patient's heart was readily resuscitated. Her immediate postoperative course was complicated by bleeding from the aortic suture line requiring reoperation 10 hours following the original procedure. Nine days later she was ambulatory and free of cardiac symptoms when a wound infection became obvious from which she eventually died, with secondary hemorrhage from the aortic suture line. Postmortem perfusion studies showed excellent relief of her stenosis with no appreciable regurgitation (Figs. 16 and 17).

An interesting and, we believe, important lesson was learned in the operative management of these 2 patients. In the first individual, it was noted that during the period of attempted resuscitation by vigorous perfusion of the coronaries, the left atrium became enormously distended with clearly an excessively high intra-atrial pressure. This, of course, was transmitted back into the pulmonary veins and eventually resulted in a marked degree of pulmonary edema and hemorrhage. As a result of this observation, in the second patient a separate catheter was placed in the left atrium at the beginning of the procedure and, during the period of coronary perfusion needed to resuscitate the heart, the blood returning to the left atrium was led off to the venous side of the pump-oxygenator. Thus, in effect, a left heart bypass was carried out during the period of resuscitation and in this way the strain on the recovering left ventricle was minimized and back-pressure effects on the lung avoided. At the same time, a large volume flow of oxygenated blood was returned to the extracorporeal system at a time when large volumes were desirable to perfuse adequately the recovery ventricular myocardium with its relatively poor coronary vasculature.

TABLE I

TYPE OF PROCEDURE	NUMBER OF CASES	STENOSIS ADEQUATELY REPAIRED (%)	RESULTANT SIGNIFICANT REGURGITATION (%)	CALCAREOUS EMBOLI (%)
Blind commissurotomy	10	60	50	40
Open commissurotomy not along leaflet interfaces	3	66	100	66
Open commissurotomy along valve leaflet interfaces	10	100	0	10

SUMMARY AND CONCLUSIONS

Thirty-six autopsy specimens of aortic valves with calcific aortic stenosis were studied before and after instrumental attempts to relieve the stenosis. The effect on stenosis and regurgitation was determined by perfusion of the valve and measurement of the pressure across it. The following conclusions were reached.

1. "Blind" commissurotomy or dilatation of a calcified and stenotic aortic valve frequently results in a forbidding degree of regurgitation, inconsistent relief of stenosis, and the release of gross calcareous emboli (Table I).

2 Débridement and commissurotomy under direct vision makes it possible consistently to relieve stenosis without producing significant regurgitation and without uncontrolled release of calcareous emboli (Table I)

3 Accurate identification of the line of leaflet fusion is the key to successful commissurotomy (Table I)

4 The commissure should not be divided beyond a point 2 mm from the aortic wall since further division will not improve stenosis and may make regurgitation worse

5 Division of only two of the three commissures results in persistent moderate aortic stenosis Division of the third commissure uniformly relieves stenosis and occasionally even decreases regurgitation

6 Failure to recognize a bicuspid aortic valve and construction of a false third commissure results in free aortic regurgitation Satisfactory relief of stenosis is accomplished in bicuspid aortic valves by division of the two commissures

The application of the above technical principles in 2 clinical cases is described

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(For Discussion, see page 615)

INTERCORONARY COLLATERALS IN NORMAL HEARTS

Sven Bellman, M.D., and Howard A. Frank, M.D., Boston, Mass.*

Detailed knowledge of the anatomy of interarterial coronary communications as they exist in normal hearts seems essential to an understanding of the natural development of arterial collaterals in response to coronary occlusion and the influence of therapeutic efforts upon this development. The presence of communications between the major coronary arterial systems has been demonstrated by many methods (see survey in Ref. 1), but in normal hearts the connecting vessels themselves are usually so small that their course can be traced only by difficult microscopic examination of cleared or corroded specimens[2] or by serial sectioning and reconstruction. The use of radiography to supplement injections and dissection has greatly increased the convenience of examination of large numbers of specimens, and the combined application of these methods has established the patterns of distribution of the major coronary arterial systems and the degree to which they intercommunicate in the hearts of many species.[1, 3-12] Standard radiographic techniques detect the passage of contrast material from one arterial bed to another but often fail to demonstrate the connecting vessels in normal hearts. The present studies apply stereoscopic microradiography[13] to permit closer examination of the form, course, distribution, and terminations of the connecting vessels. These observations were undertaken primarily to serve as a basis for studies of the early stages in the development of collateral vessels in response to experimental occlusion of coronary arteries.

MATERIAL AND METHODS

The observations to be presented are based on a study of the coronary arteries of 80 hearts of healthy young adult animals of both sexes, and a small number of human hearts (8) from young patients without coronary disease or other disorders known to stimulate intercoronary collaterals.[1] The observations were confined to the ventricular branches of the coronary systems. The human specimens studied in greatest detail were those of two 17-year-old men and one 24-year-old woman who died abruptly (accidental head trauma or spontaneous

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Read at the Thirty-eighth Annual Meeting of the American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

*Research Associate in Surgery, Beth Israel Hospital and Research Fellow in Surgery, Harvard Medical School; visiting from the Department of Surgery, Serafimerlasarettet and the Department for Medical Physics, Karolinska Institutet, Stockholm, Sweden.

subarachnoid hemorrhage) without antecedent illness However, the findings were similar in the hearts of other young patients without coronary disease who died after more protracted illness

For the study, a radiopaque mass was injected into a single arterial trunk or branch in each heart The human hearts were injected at autopsy within 12 hours after death Most animal specimens (the 28 dog hearts, 10 rabbit hearts, 21 rat hearts, and 2 hearts from 6 week old pigs raised in the laboratory) were injected fresh These animals were given heparin and sacrificed with an overdose of nembutal intravenously, the hearts were removed and injected immediately The 19 hearts from adult pigs studied were obtained freshly removed at the slaughterhouse, they were injected within 1 to 2 hours after the animals were slaughtered

The raidopaque mass was injected via a cannula tied in place in the artery chosen, no ligatures were placed about adjacent arteries or coronary ostia The proximal part of the anterior descending coronary artery, just below the origin of the left circumflex artery, was the place most frequently chosen for cannulation, it was used in all human hearts Other large components of the coronary system, such as the common left coronary, the left circumflex, and the right or subdivisions of the left coronary system, such as the septal artery or individual branches near the outer surface down to 0 5 to 1 mm in diameter, were injected in a number of specimens In rat hearts, the region of distribution of the anterior descending coronary artery was also studied by applying a suture ligature on this vessel at the level of the pulmonary conus and injecting contrast mass into the coronary ostia via the aorta

The contrast material was a freshly prepared 40 per cent (by weight) suspension of finely divided barium sulfate (Micropaque*) in a 2 5 per cent solution of gelatin in water It was warmed to +40° C before the injection and the hearts were brought to a similar temperature by immersion in warm saline solution Precautions were taken to avoid sedimentation or setting of the mass in the tubing during injection An injection period of 5 to 10 minutes at a pressure of 50 to 70 mm Hg provided maximum filling of the vessels The hearts were then cooled in iced saline to set the mass, and kept cool until they were opened, unrolled, and fixed

In unrolling the hearts for microradiographic study, the back wall of the left ventricle was usually incised from the root of the aorta to the apex, and the septum divided so that its anterior half remained attached in the mid-portion of the opened out anterior wall, and the posterior half remained with the border of the right ventricle In individual specimens, however, other planes of division were chosen to show the intact posterior wall, the joining of the vessels at the apex, the intact septum in profile, or to permit detailed examination of a small portion of the ventricular wall The gross appearance of the heart surface and the injected vessels was noted and often recorded photographically The unrolled specimens were pinned flat on cork mats and fixed overnight in 10 per cent formalin

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Microradiograms were taken using a Machlett AEG-50 microradiography tube, energized at 15 to 25 kV. and 15 to 17 mA., using a focus to film distance of 50 cm. and Agfa Printon Rapid or Gevaert Duplo Ortho film as photographic material. The exposure times ranged between 2 and 20 minutes. The films were developed in undiluted Kodak D 19 developer at room temperature for 1.5 to 3 minutes. For x-ray protection, the microradiograms were taken within a metal box into which the end of the x-ray tube projected. Variations in soft tissue shadow were compensated for by immersing large and uneven specimens during the exposure in saline in a special container with a thin celluloid bottom. The specimen was held immobile against the bottom of the container; this in turn rested on the photographic film, wrapped in black paper.

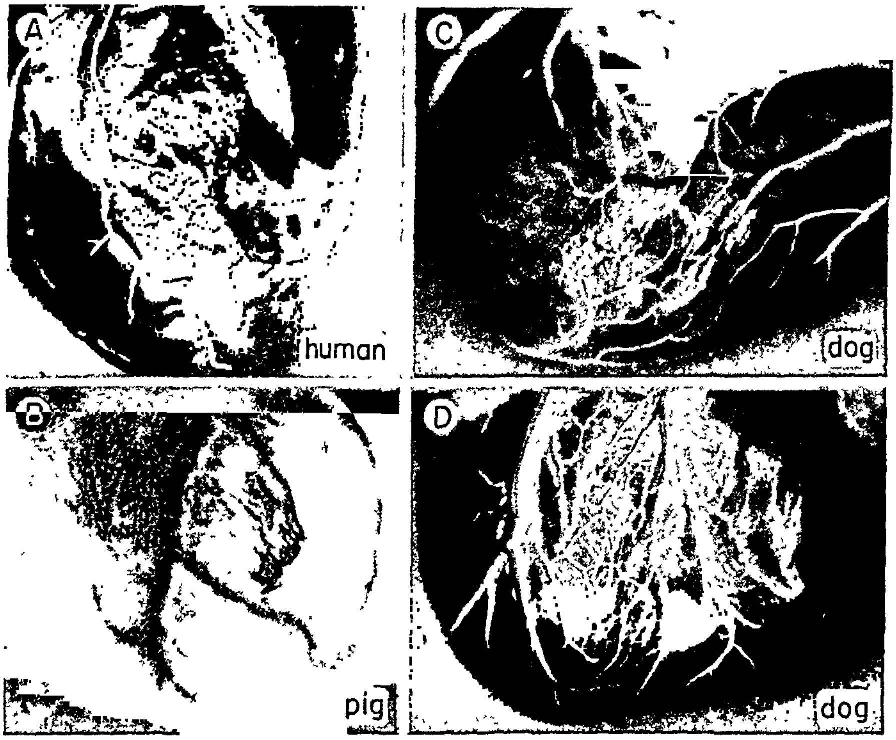

Fig. 1.—Photographs of anterior surfaces (*A*, *B*, *D*) and apex (*C*) of hearts injected through the anterior descending coronary artery.

The surface of the human heart (*A*) shows only the major trunk and some primary branches, surrounded by a considerable quantity of fat.

The surface of a 6-week-old pig heart (*B*) shows little but the primary branching of the injected trunk and even these vessels are somewhat obscured as they run beneath the superficial layers of the myocardium. In the hearts of adult pigs, the covering layer of myocardium was thicker, and much less of these vessels could be seen.

The dog heart (*C* and *D*) shows the characteristic network of surface vessels connecting branches of the injected artery with each other and with right and left circumflex coronary arteries.

Subdivisions of the main specimens were microradiographed without saline for finer detail. These specimens rested on a cellophane sheet supported by a rigid frame and the wrapped films were slid underneath the sheet.

All specimens were microradiographed stereoscopically, using successive exposures. The saline container with the submerged specimen, or the framed cellophane sheet carrying the unsubmerged specimen, was moved 10 to 30 mm. along a straight track in the metal box before the second microradiogram was taken. The microradiographic technique used gave unit-scale stereomicroangiograms. These were viewed in a Nife mirror stereoscope, which permitted examination of the microangiograms unmagnified or enlarged 4 times. Finer detail, necessary for the finest injected vessels, was brought out by photographic enlargement, up to 20 times, of portions of the initial microangiograms.

RESULTS

Macroscopic Observations.—

Observation of the hearts during and after injection of contrast mass in all cases disclosed filling of all parts of the injected system that were visible on the outer surface. In the human hearts and pig hearts only the major trunks and some primary branches of the injected coronary arteries were visible on the surface (Fig. 1, *A* and *B*); in the pig hearts even these vessels were covered through much of their course by a thin layer of myocardium and showed rather poorly. In the dog hearts the trunks and a great number of primary, secondary, and tertiary arborizations showed clearly through the epicardium, with many fine vessels forming reticular connections between branches of the injected system and also linking the injected system to arborizations of adjacent systems (Fig 1, *C* and *D*). The extensive arterial filling within the ventricular walls produced a general whitening of the muscle in the region of distribution of the injected artery.

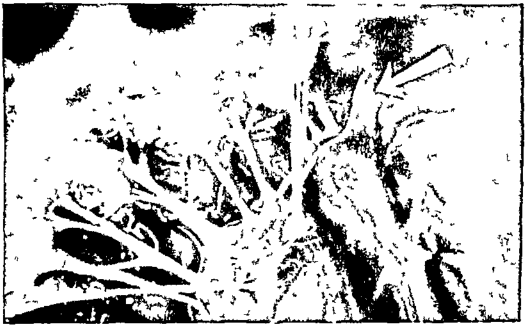

Fig 2—Pig heart Photograph of interior of right ventricle showing an arterial branch traversing part of the ventricle from the posterior wall to the apex of a papillary muscle Injection through right coronary artery

On the inner surface, which was inspected after unrolling the heart, segments of medium-sized or rather large arterial branches were often visible just beneath the endocardium in both ventricles and especially on the right ventricular aspect of the septum. In the latter region, some part of the septal artery was usually visible just under the endocardium in all species studied. Small arterial branches frequently reached the endocardial surface at the apices of papillary muscles and ramified there. Slender [illegible] lar

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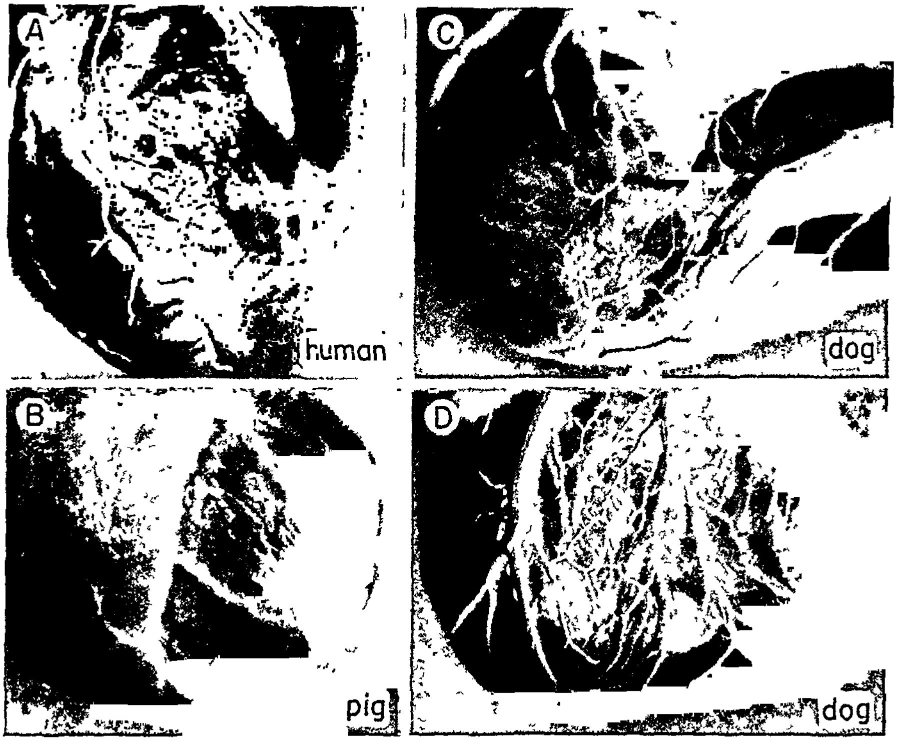

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of muscle frequently contained a readily visible arterial branch, and in some instances the artery alone constituted the major portion of the bridge (Fig 2) Such bridges were seen in all species studied, but in the pig they were especially long, often running almost across the middle of the ventricular cavity

Contrast material injected into the trunk or a branch of any of the major systems (right coronary, anterior descending, or left circumflex) appeared in surface branches of one or both of the other systems in all dog hearts The human hearts were injected through the anterior descending artery, they

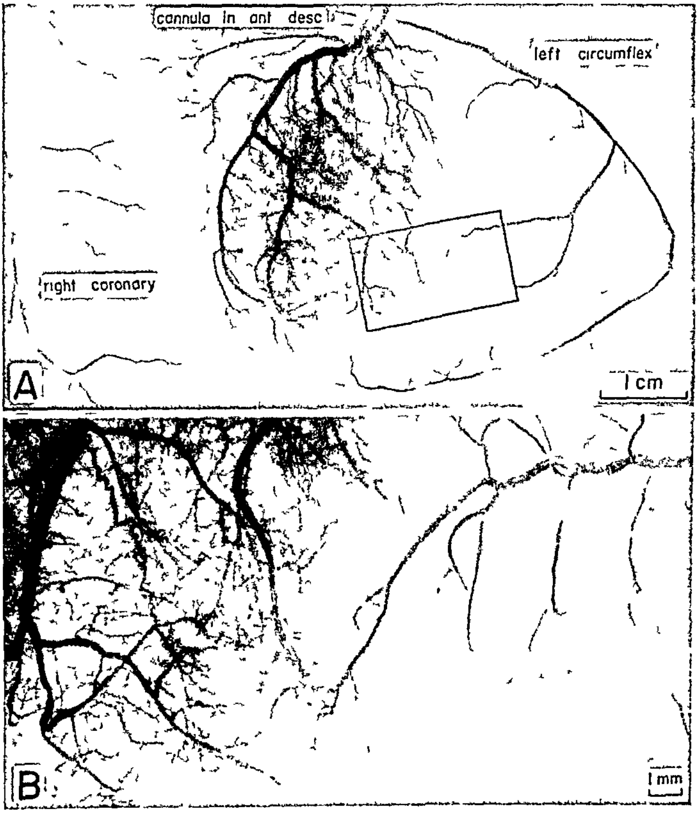

Fig 4 —Dog heart. Microangiograms showing over all pattern of distribution of contrast mass following injection into the anterior descending coronary artery The dense filling of fine vessels within the distribution of the injected artery contrasts with the sparse filling in the regions of distribution of arteries injected only by way of communicating vessels

B is a magnified view of the area marked in *A* and shows in greater detail the zone of dense injection about each small branch of the anterior descending artery The outward extension of the arterial subdivisions is more pronounced than in the pig hearts (see Fig 3) and gives the border a serrated contour

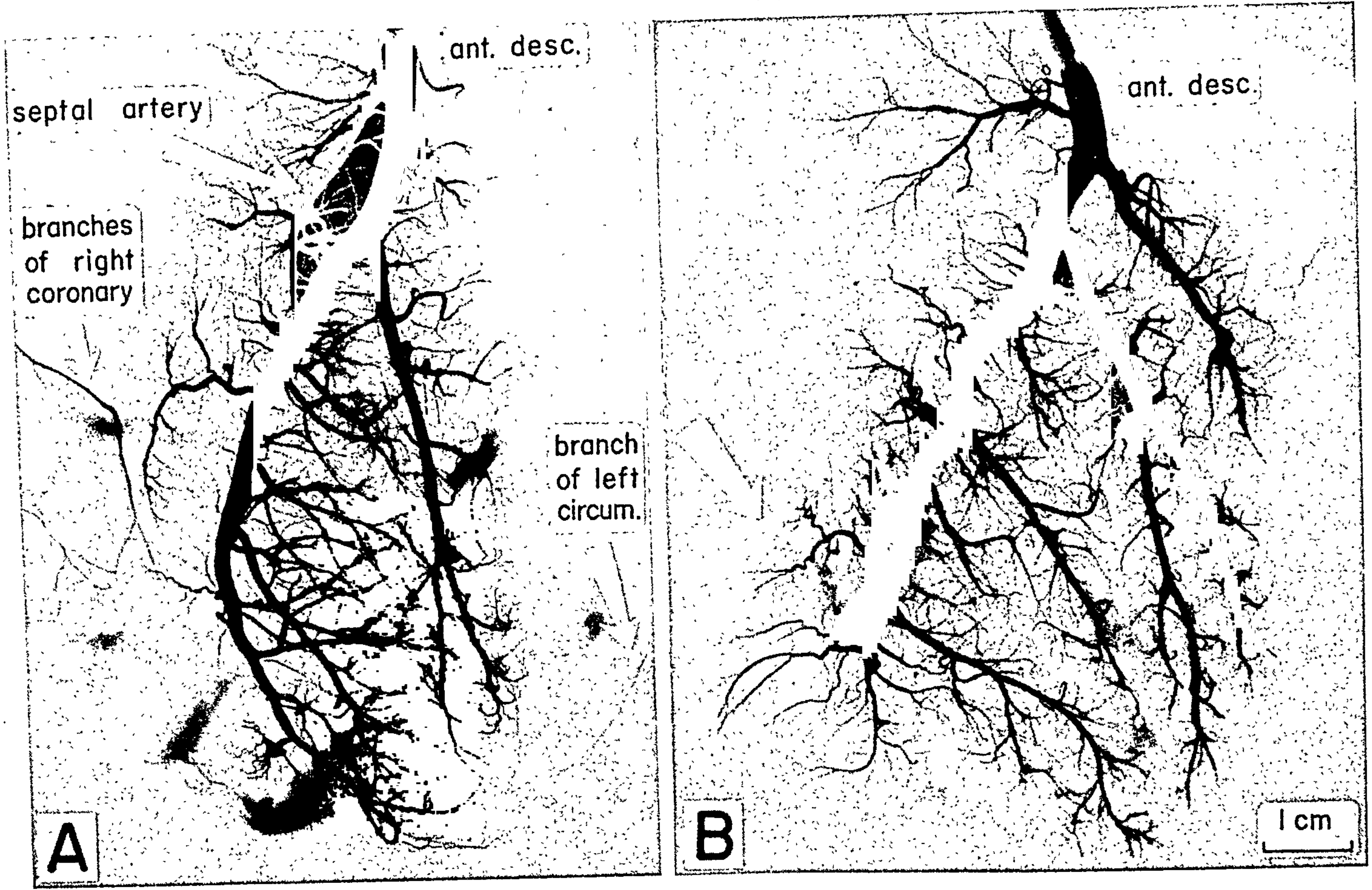

Fig. 3.—Pig heart. Microangiograms of 2 hearts injected through the anterior descending coronary artery just below the origin of the left circumflex, showing typical patterns. Specimen *B* shows a large upper branch and a series of short branches to the right ventricle; one is definitely tortuous (*arrow*).

Sparse contrast filling in branches of right and left circumflex coronary arteries is seen in *A*; in *B* there is no passage of mass into adjacent coronary systems.

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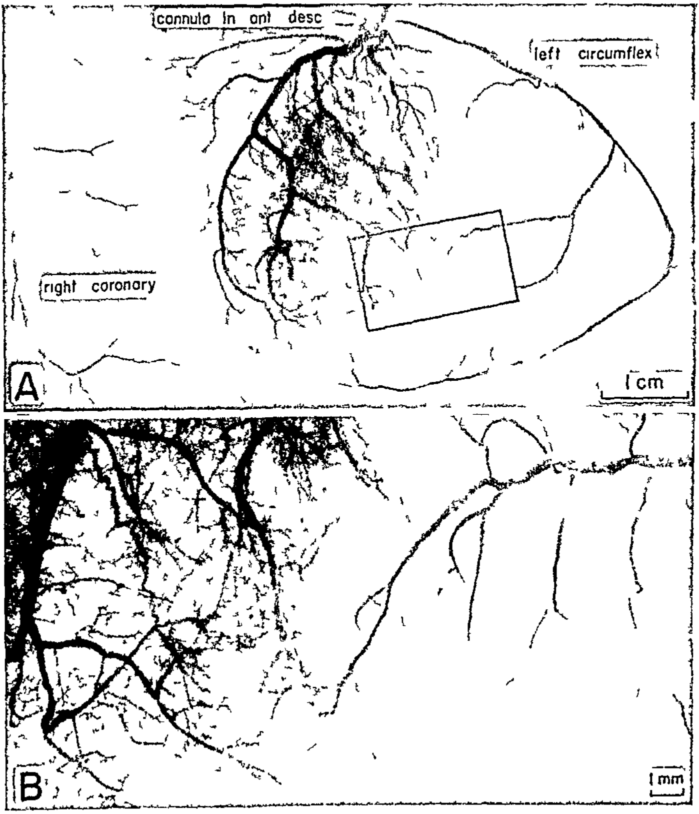

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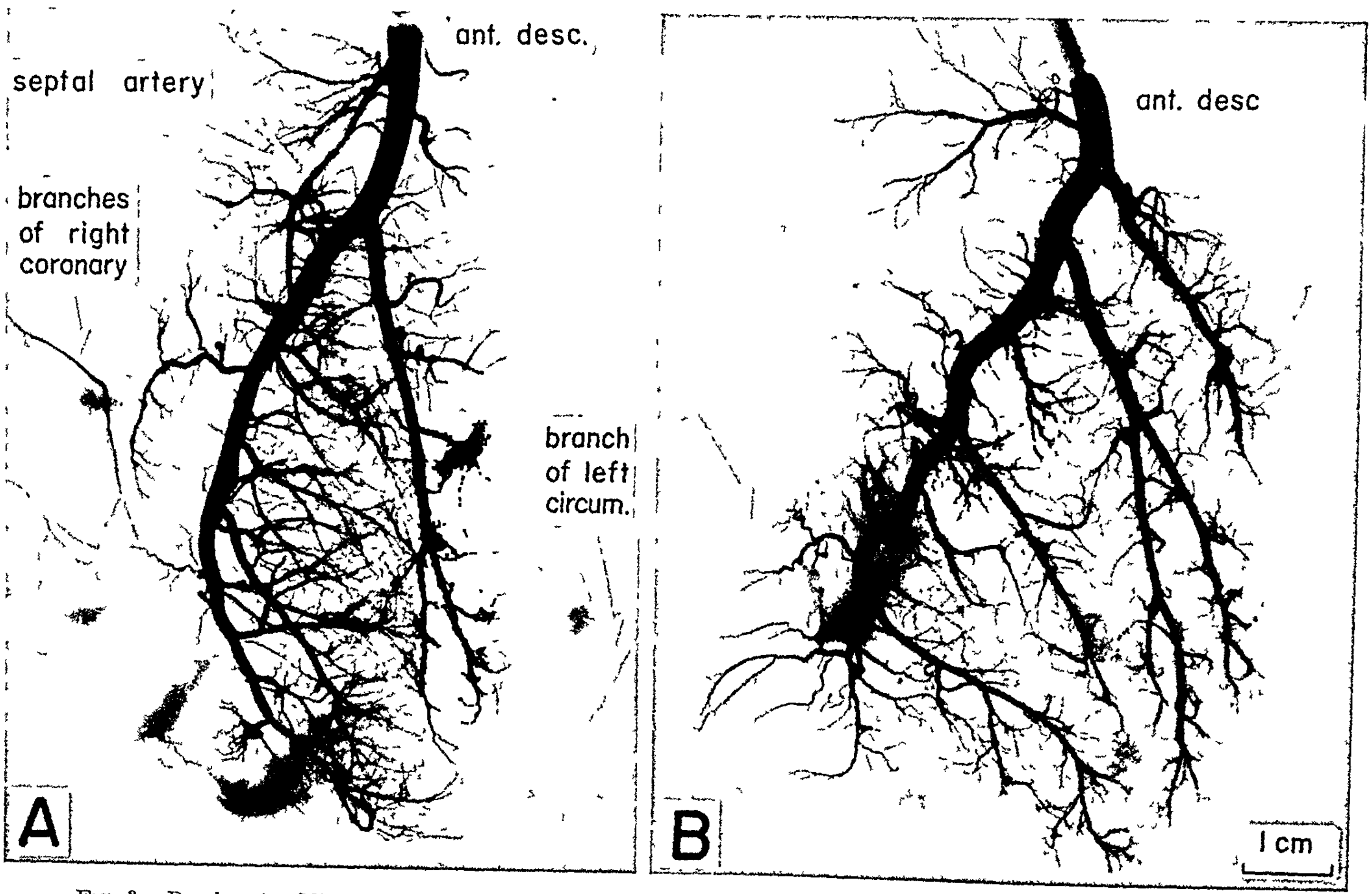

Fig 3.—Pig heart. Microangiograms of 2 hearts injected through the anterior descending coronary artery just below the origin of the left circumflex, showing typical patterns Specimen *B* shows a large upper branch and a series of short branches to the right ventricle; one is definitely tortuous (*arrow*)

Sparse contrast filling in branches of right and left circumflex coronary arteries is seen in *A*, in *B* there is no passage of mass into adjacent coronary systems

of muscle frequently contained a readily visible arterial branch, and in some instances the artery alone constituted the major portion of the bridge (Fig 2) Such bridges were seen in all species studied, but in the pig they were especially long, often running almost across the middle of the ventricular cavity

Contrast material injected into the trunk or a branch of any of the major systems (right coronary, anterior descending, or left circumflex) appeared in surface branches of one or both of the other systems in all dog hearts The human hearts were injected through the anterior descending artery, they

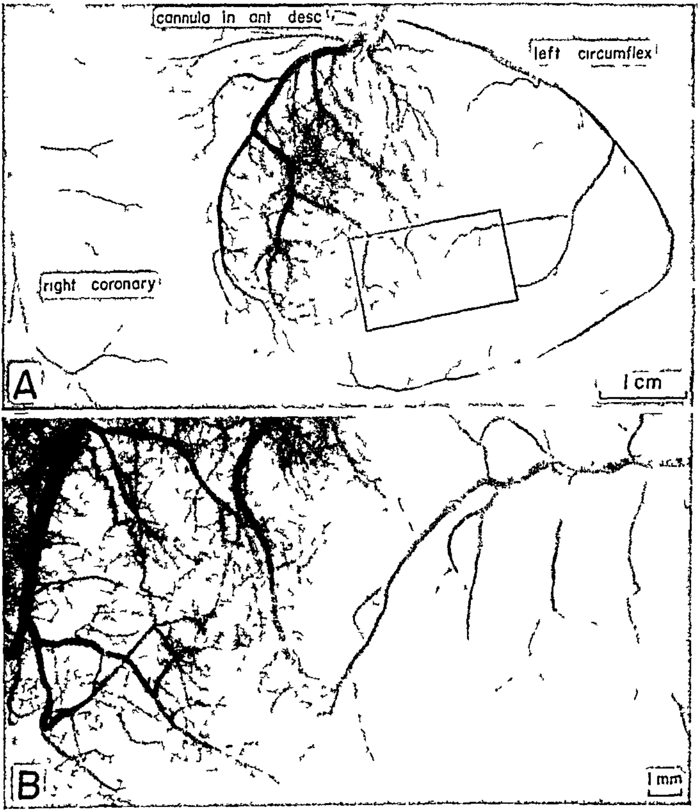

Fig 4—Dog heart. Microangiograms showing over all pattern of distribution of contrast mass following injection into the anterior descending coronary artery The dense filling of fine vessels within the distribution of the injected artery contrasts with the sparse filling in the regions of distribution of arteries injected only by way of communicating vessels

B is a magnified view of the area marked in *A* and shows in greater detail the zone of dense injection about each small branch of the anterior descending artery The outward extension of the arterial subdivisions is more pronounced than in the pig hearts (see Fig 3) and gives the border a serrated contour all showed similar passage of the contrast mass. Retrograde flow of mass through the ostia of the secondarily injected arteries was frequently seen. In the pig hearts, and also in the rabbit hearts, passage to adjacent arteries was sparse, and radiographic examination was usually required to determine the presence of contrast material in their branches (Fig. 3). No mass was seen to pass from one coronary system to another in rat hearts.

The mass did not appear in the veins.

Microangiographic Observations.—

General patterns: The course of vascular pathways could be traced completely to the limit of contrast penetration, i.e., to ramifications 20 to 30 micra in diameter as measured in microangiograms of the fixed specimens. Contrast penetration to this limit was quite uniform in the region of arborization of the injected coronary system; the dense pattern of small vessels corresponded to the areas of whitening seen on the surfaces of the heart. In all species examined, this primarily injected system had a quite sharp border which stood out clearly throughout the full thickness of the ventricular walls in the stereo-models; it was apparent that a zone of high vascular resistance delimited the region supplied by any one coronary arterial system or its main subdivisions. The border between an injected system and adjacent ones was smooth in pig hearts, and more serrated in dog and human hearts; this was related to a difference in orientation of the medium-sized arborizations as they approached the border (Figs. 3 and 4). In the pig hearts, the zones of

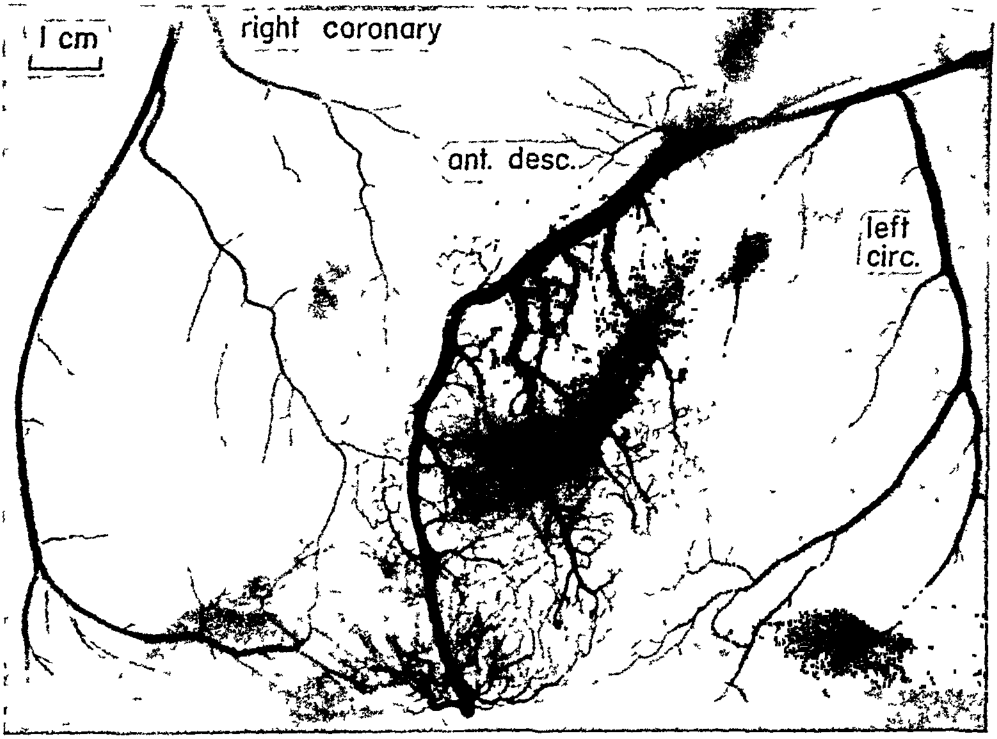

Fig. 5.—Human heart. Microangiograms of opened and flattened heart injected through the anterior descending coronary artery, showing the filling of the fine vessels in the region of distribution of the injected artery, and contrast mass in the major branches and trunks of the left circumflex and right coronary arteries (The cannula crosses the origin of the left circumflex artery at the right upper corner)

distribution of individual arterial branches were so distinct that narrow bands of nearly uninjected tissue were found between the more widely spaced secondary branches, particularly within the anterior descending system. In dog and human hearts there were no such clear zones within the region of primary injection, but the terminal visible arborizations of individual branches formed a contour immediately adjacent to, yet distinct from, the periphery of adjacent arborizations. Very few branches passed across these borders.

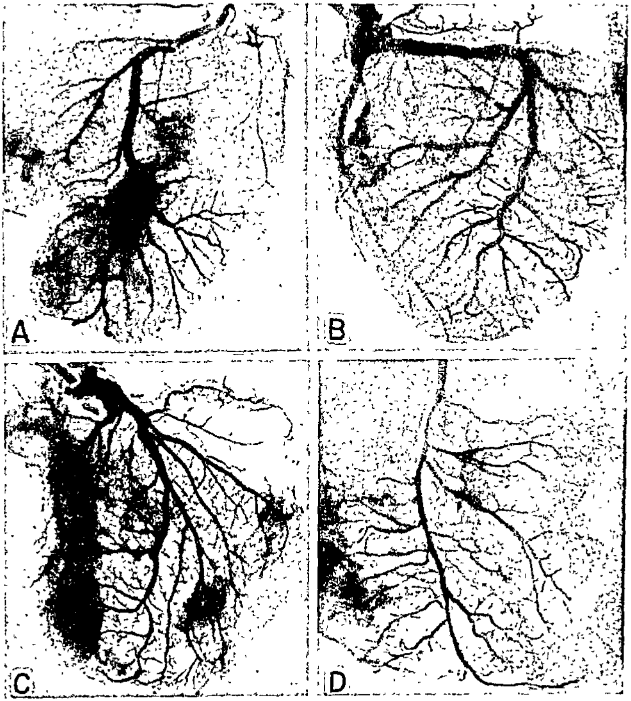

Fig. 6.— Microangiograms of rabbit and rat hearts.

A, Rabbit heart showing typical pattern of the injected anterior descending artery, and contrast mass in branches of adjacent coronary system.

B, Rabbit heart injected through left coronary artery showing anterior descending and circumflex arteries.

C, Rabbit heart injected through left coronary artery showing a large portion of both ventricles supplied by a common left artery without a circumflex division.

D, Rat heart showing typical pattern of injected anterior descending artery.

In contrast to the extensive filling and uniform distention of the vessels of the primarily injected arterial system, the branches of adjacent systems, which received radiopaque mass through communicating vessels, were less extensively and less evenly filled and were not distended, [illegible] m [illegible] free to escape through their major trunks and coronary os[illegible] all showed similar passage of the contrast mass. Retrograde flow of mass through the ostia of the secondarily injected arteries was frequently seen. In the pig hearts, and also in the rabbit hearts, passage to adjacent arteries was sparse, and radiographic examination was usually required to determine the presence of contrast material in their branches (Fig. 3). No mass was seen to pass from one coronary system to another in rat hearts.

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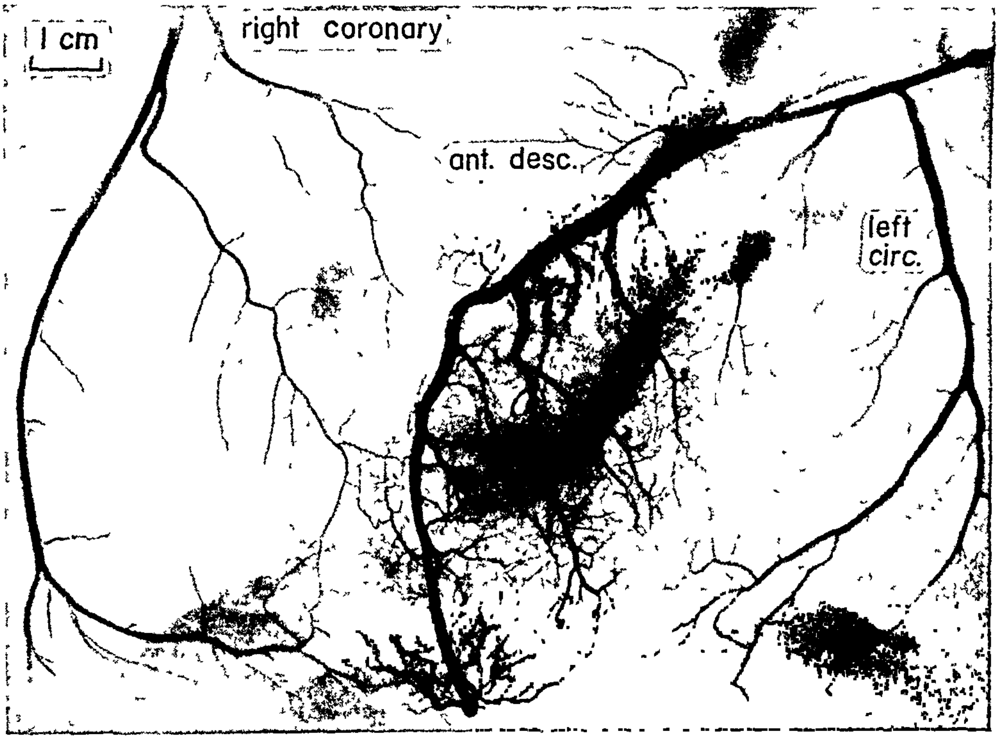

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The branching and regional distribution of the major coronary systems in the human, dog, and pig hearts were essentially as has been found by others. The rat hearts also had a similar basic pattern of right and left coronary systems with descending and circumflex divisions and had strong septal branches. The rabbit hearts, in general, conformed to this pattern but in several the left coronary artery did not divide into definite descending and circumflex

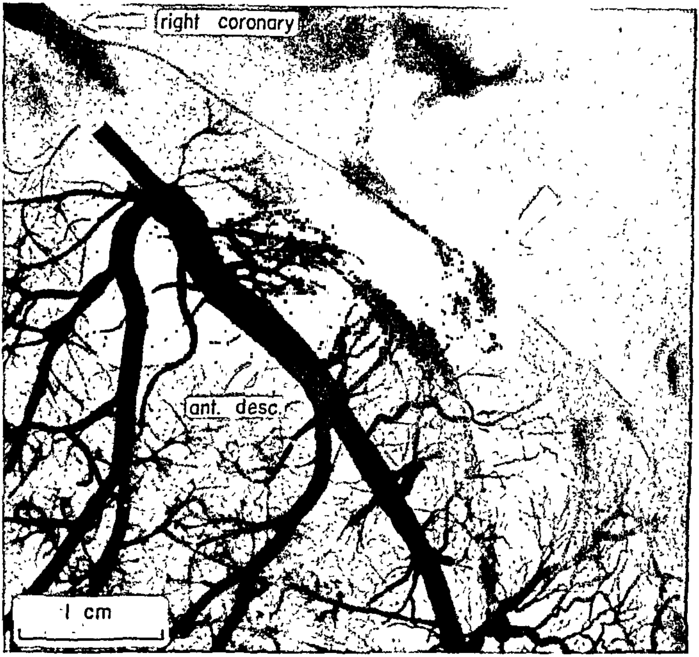

Fig. 8.—Pig heart. Microangiogram showing a long slender vessel in a trabecular muscle bridge in the lumen of the right ventricle *(unmarked arrow)*. The vessel arises from the right coronary artery near its ostium *(upper left corner)*; lateral and end arborizations connect at the lower end of the trabecula with fine branches of the anterior descending coronary artery.

The contrast mass was injected into the anterior descending artery through the cannula seen near the upper left corner.

Fig. 7.—Pig hearts. Microangiograms of anterior wall of right ventricle, trabecular bridge, and papillary muscle from right ventricle.

A, Communications between the anterior descending artery, which received the injection *(lower right)*, and branches of the right coronary artery. The major branches were at the outer surface but the communicating vessels lay deep near the endocardial aspect of the ventricular wall.

B, Trabecular bridge which extended across the chamber of the right ventricle and contained communications from the injected anterior descending artery to right coronary branches at the base of a papillary muscle.

C, *Papillary muscle in chamber of right ventricle containing* intercommunicating ramifications of septal branches from the anterior descending artery and also communications to the right coronary in the wall of the ventricle *(upper right)*.

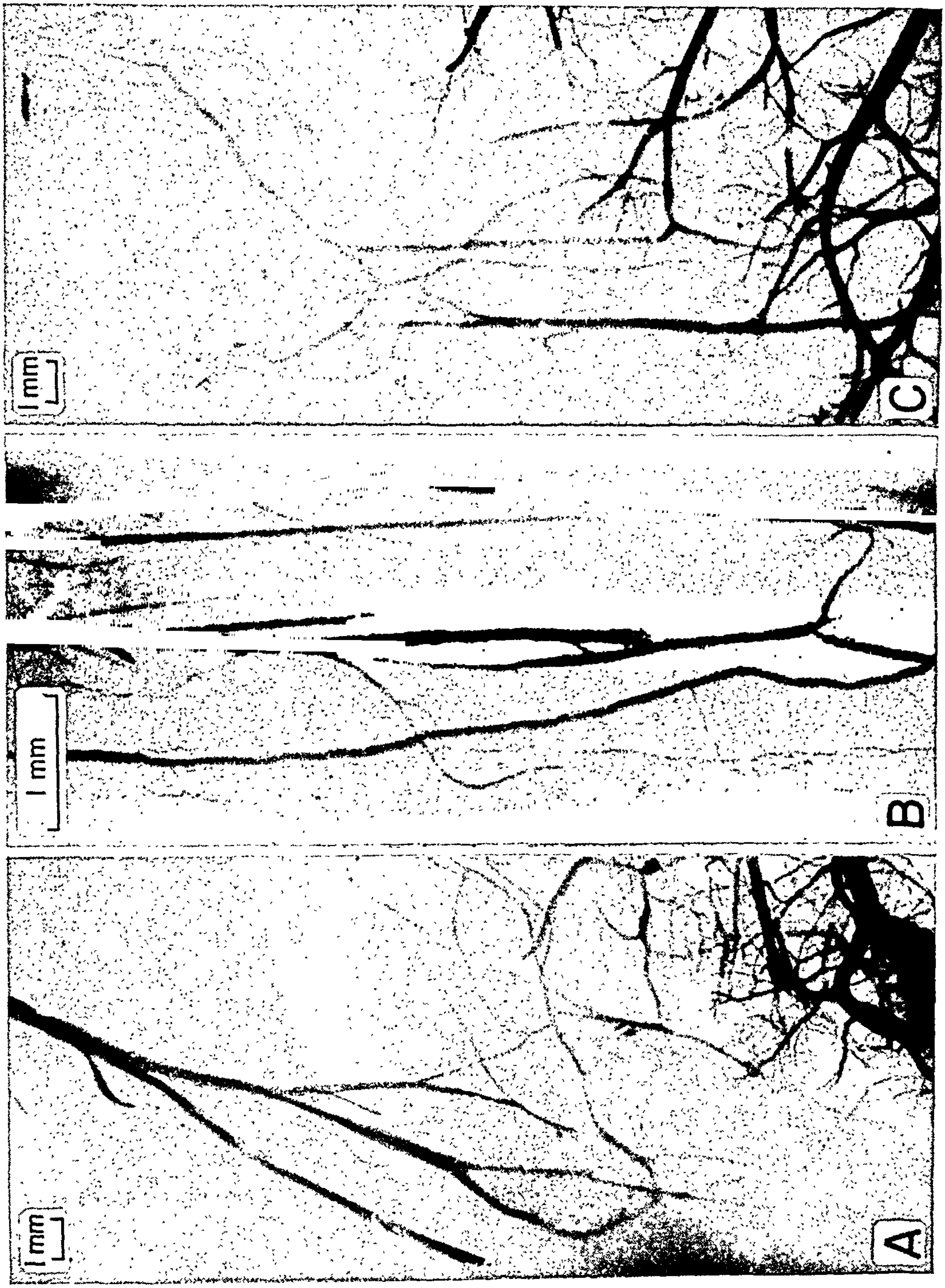

Fig. 7.—*For legend see opposite page.*

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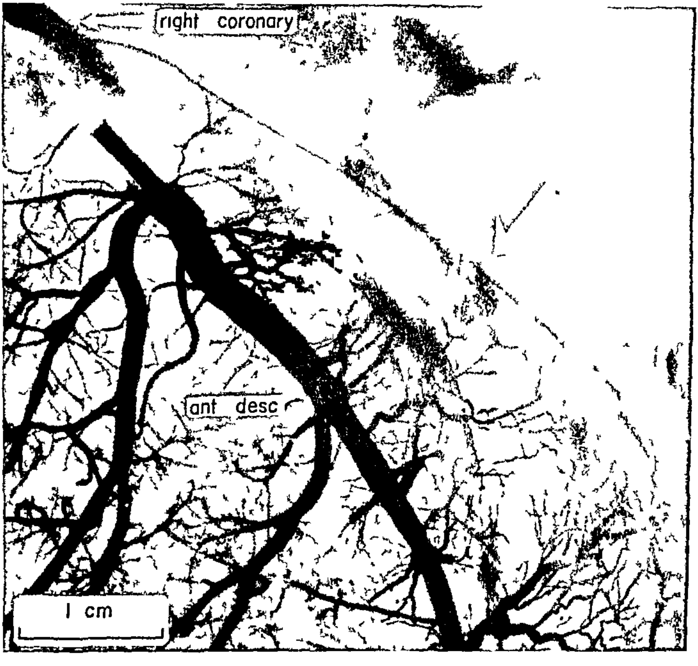

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C, Papillary muscle in chamber of right ventricle containing intercommunicating ramifications of septal branches from the anterior descending artery and also communications to the right coronary in the wall of the ventricle (*upper right*).

components. In hearts with this left coronary pattern, nearly all of the anterior wall, the left border, and much of the posterior wall of both ventricles were supplied by a series of branches from the left coronary trunk (Fig. 6). An occasional rat heart also had a dominant left coronary pattern.

Our observations were directed mainly toward the distribution of the anterior descending coronary artery; the trunk of this artery in human, pig,

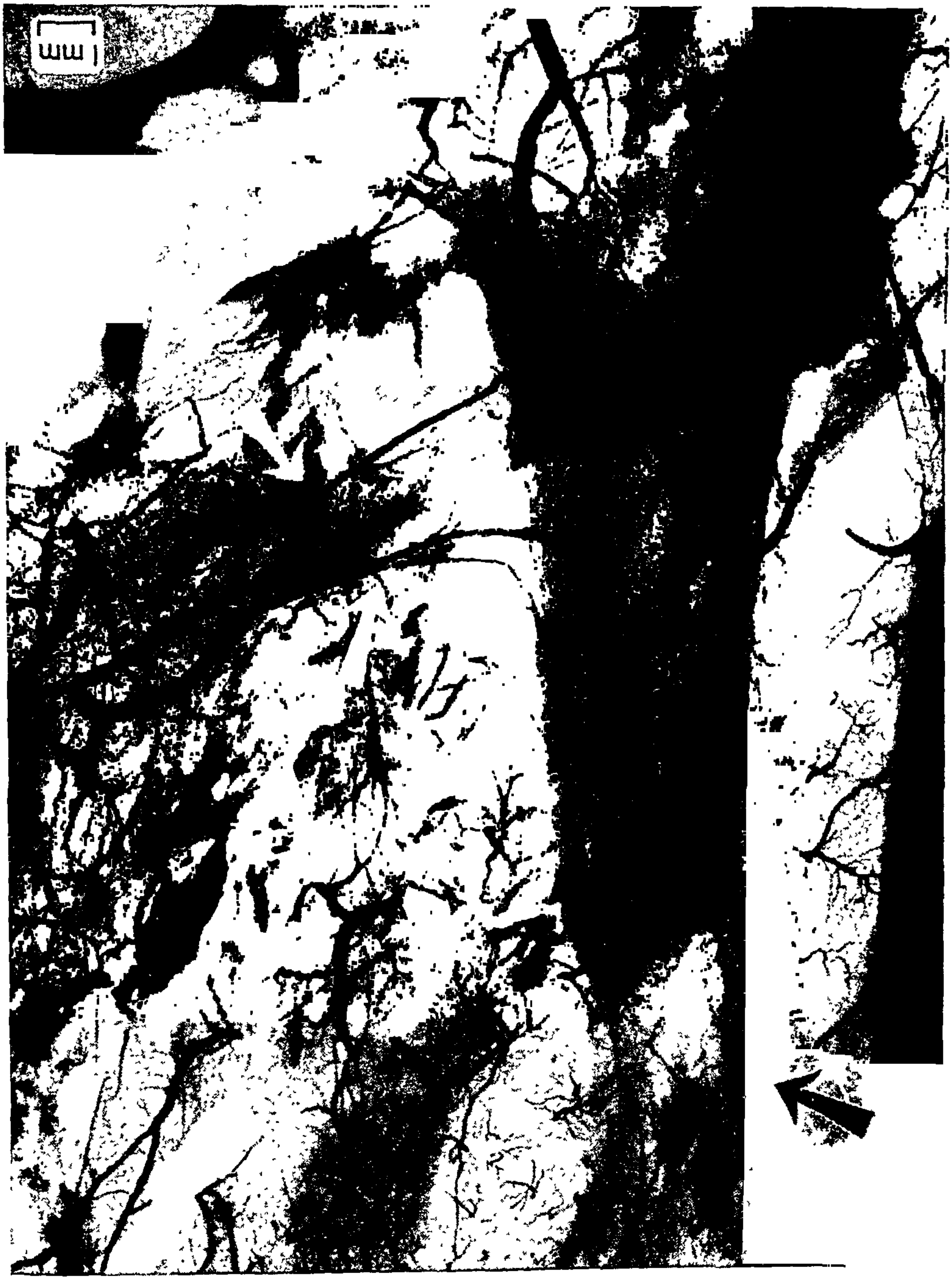

Fig. 9.—Human heart. Excised papillary muscle and neighboring trabecular ridges and bridges. The vessels within the papillary muscle are filled by injection of the anterior descending artery. Communications are seen within trabecular bridges between the apex of the papillary muscle and vessels within the ventricular wall (*left upper arrow*) and between the base of the papillary muscle and vessels of the septum (*right arrows*).

and dog hearts ran toward the apex on or just below the anterior surface of the left ventricle, adjacent to the anterior attachment of the interventricular septum, sometimes passing about the apex to the lower posterior aspect of the heart. Large, widely spaced primary branches ran obliquely downward across the anterior face of the left ventricle. In human and pig hearts, only small portions of these oblique branches were visible on the surface, however, the

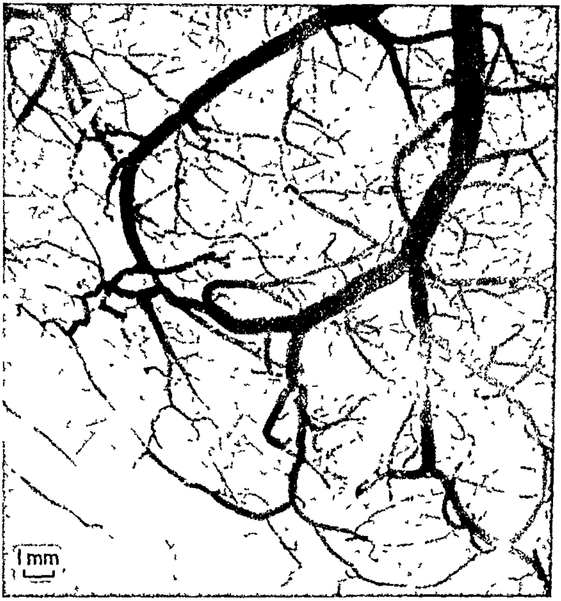

Fig 10.—Dog heart Microangiogram showing between
branches of the anterior descending coronary artery arrows
Some communications are superficial, others are deep Examples
of the "end-to-end" and the "long, uniform diameter" en

radiographic appearance was quite similar in all species studied Many secondary branches left the oblique arteries to pass either directly into the depth of the myocardium, or first laterally for some distance and then toward the endocardial surface. In addition to the large oblique branches, the main trunk of the anterior descending artery in all species gave off a closely spaced series of smaller branches which passed laterally into the anterior walls of the left and right ventricles and posteriorly nearly at right angles into the septum. One or two large distinct "septal arteries" arising from the anterior descending or common left coronary artery were quite constantly found in dog and rat hearts (in the rat frequently arising from the right coronary artery) and were also present in most of our human hearts. T er, a series of uniform branches usually led from the to the septum. A large branch of the anterior descending artery usually arborized widely in the upper aspect of the anterior wall of the right ventricle (see Figs. 3, *B*, 4, *A*, and 5), and several smaller branches ramified irregularly or formed a series of uniform bushy arborizations in the lower anterior wall of the right ventricle. The branches to the right arising from the mid-portion of the anterior descending trunk, whether leading to the right ventricular wall or to the right face of the septum, were frequently distinctly tortuous as were their arborizations (see Fig. 3).

Passage of contrast mass into cardiac veins was not observed in any species.

Intercoronary arterial connections: Contrast mass did not pass from the injected coronary system into adjacent ones in rat hearts, but did reach the branches and sometimes also the trunks of adjacent systems in 3 of 10 rabbit hearts, and in 14 of 19 pig hearts. Trunks and numerous branches of adjacent systems were outlined by passage of mass in all dog and human hearts, although not with the dense fine-vessel filling of the zone of primary injection. One of the pig hearts showed the free passage of contrast mass seen in the dog and human hearts, in 6 the mass entered a few adjacent branches but did not reach the trunks, and in 7 there was only a minimal penetration of mass into

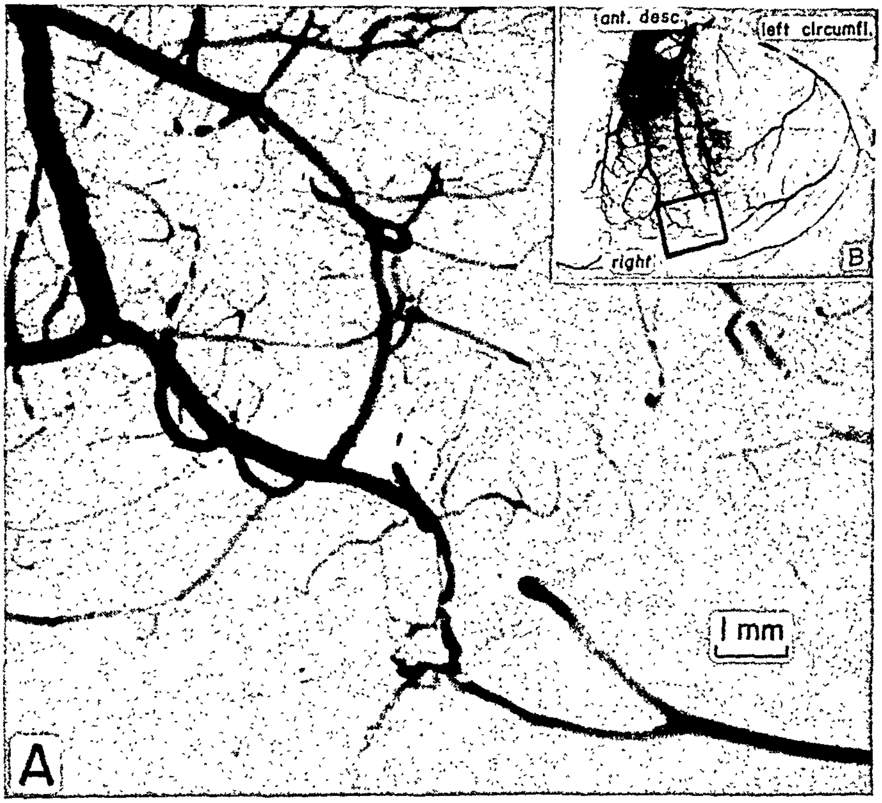

Fig. 11.—Dog heart. Microangiogram showing communications between terminal branches of the injected anterior descending coronary artery and of the left circumflex artery in the anterior apical portion of the left ventricle. The location of the magnified field is marked in the inset.

A large communication is formed by the continuity of a branch of the anterior descending artery with a branch of the left circumflex. Several finer connections can also be seen.

one or two fine twigs of adjacent systems. In none of the hearts studied was the run-off of contrast mass to neighboring arterial systems so free as to interfere with the filling of the fine arborizations of the injected system

The pathways through which contrast mass passed from one system to another could usually be traced stereoscopically without difficulty in the primary microangiograms of dog, pig and human hearts Some connecting vessels could be seen without magnification, but the fourfold magnification of the stereoscope was necessary for adequate study of the majority of the connections found Higher magnification, obtained by photographic enlargement, was useful in separating superimposed vessels and in establishing continuity, but did not bring out many additional connections in these species. High magnification was necessary, however, for demonstration of the connections in the rabbit hearts; these vessels were about 20 to 30 micra in diameter, i e, at the limit of penetration of contrast mass, and were not always outlined in complete continuity Those observed were situated within the ventricular walls, and except for their generally smaller size resembled those of dog and human hearts, to be described.

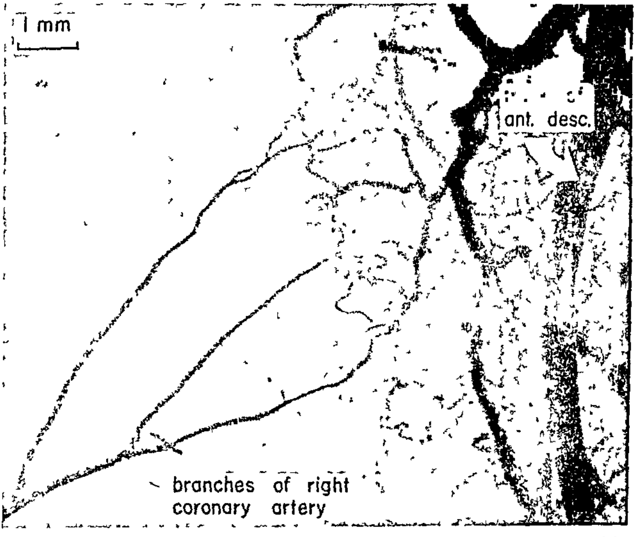

Fig 12 —Dog heart Microangiogr between terminal branches of the injected anterior descending ie right coronary artery These communications are located just the anterior wall of the right ventricle and are typical of the area of the dog heart

The intersystem connections found in pig hearts were located intramuscularly, frequently linking fine vessels arborizing in papillary muscles and trabeculae with penetrating branches from the anterior or posterior surface Other communications were occasionally demonstrat th ts of the ventricles near the apex (Fig 7, A) and at the pos atri tricular sulcus. The trabecular muscle bridges contained long, slender arteries which entered at one pedicle, gave off a few small branches in the bridge, and divided into their terminal arborizations in the other pedicle, where connections could often be traced to adjacent arterial systems (Figs. 7, *B*, and *C*, and 8). Connections within the injected arterial system were also found in most pig hearts, usually also in relation to papillary or trabecular vessels. The number of such communications in any single heart, however, was never large; often no more than one or two could be demonstrated.

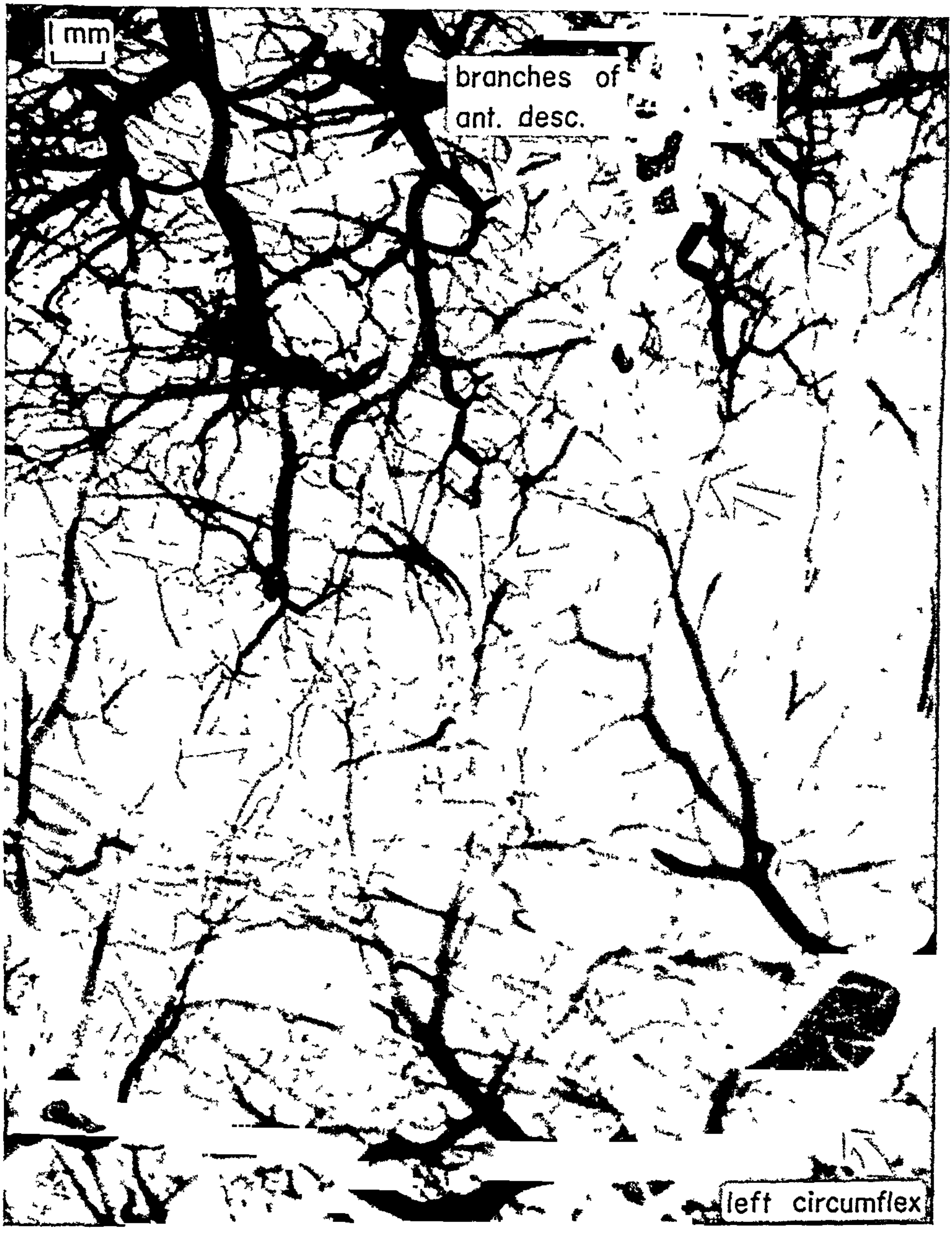

Fig. 13.—Human heart. Microangiogram of portion of anterior wall of left ventricle near the apex. Injection through anterior descending artery. The arrows indicate some of the many communications between this and the left circumflex artery. The transverse vessels seen in the lower half of the field are connecting vessels lying in trabeculae on the inner aspect of the ventricular wall.

In dog and human hearts, numerous intersystem connections were readily found throughout the marginal zones about the region of primary injection. Most connecting vessels were located near the epicardial or endocardial surfaces. Those near the inner surface were for the most part related to papillary and trabecular vessels similar to those seen in pig hearts but considerably more numerous (Figs. 9 and 13). Those near the outer surface of the dog hearts included the network of surface connections seen directly and also other connecting vessels of similar appearance within the substance of the muscle (Figs. 10 to 12). The latter remained for the most part parallel to the surface, but some dipped into deeper muscle layers, while a few, arising and terminating in intramuscular branches, rose to the subepicardial plane for much of their course. The microangiograms of human hearts showed a similar network of superficial connections (Figs. 13 and 14) which, however, did not

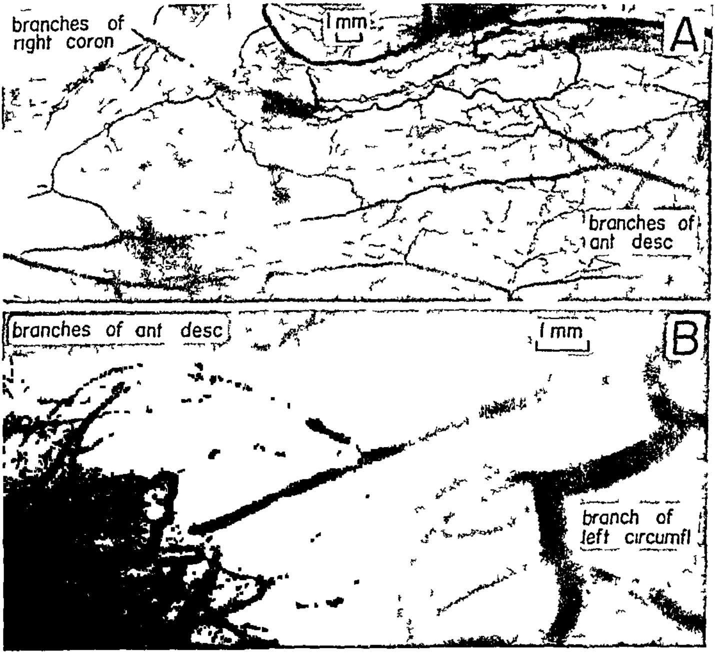

Fig. 14.—Human heart. Microangiograms following injection through anterior descending coronary artery.

A, Anterior wall of right ventricle showing slender communications between the anterior descending and right coronary arteries.

B, Apex of heart showing communications between the anterior descending and left circumflex arteries. The direct terminal joining of a branch from each system is seen as well as at least two slender connecting vessels.

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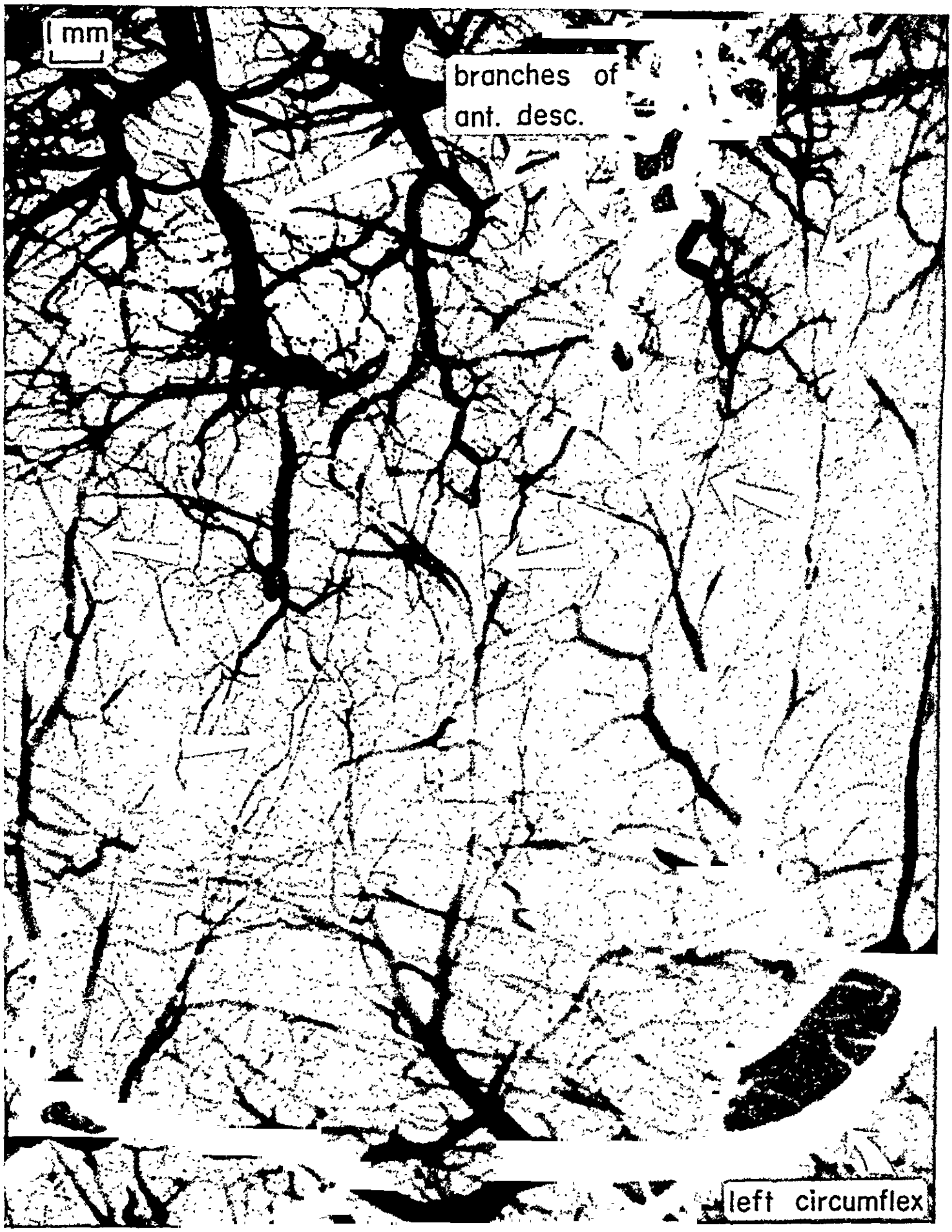

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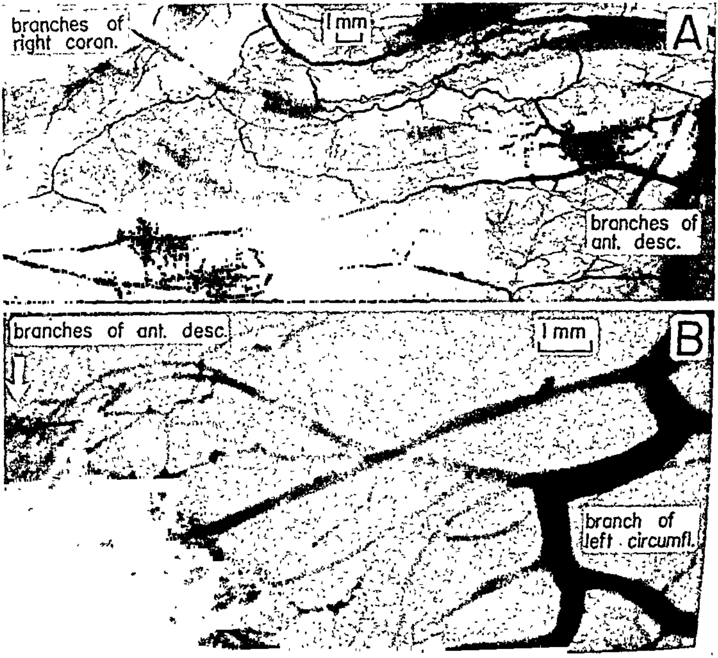

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A, Anterior wall of right ventricle showing slender communications betwen the anterior descending and right coronary arteries.

B, Apex of heart showing communications between the anterior descending and left circumflex arteries. The direct terminal joining of a branch from each system is seen as well as at least two slender connecting vessels.

quite reach the epicardial surface. Other intersystem and intrasystem communications were found at all depths in the walls of the ventricles and the septum (Fig. 15) of dog and human hearts, some running in the plane of the surface, others changing depth in their course, occasionally running almost perpendicularly to the plane of the ventricular wall to connect branches at outer and inner surfaces.

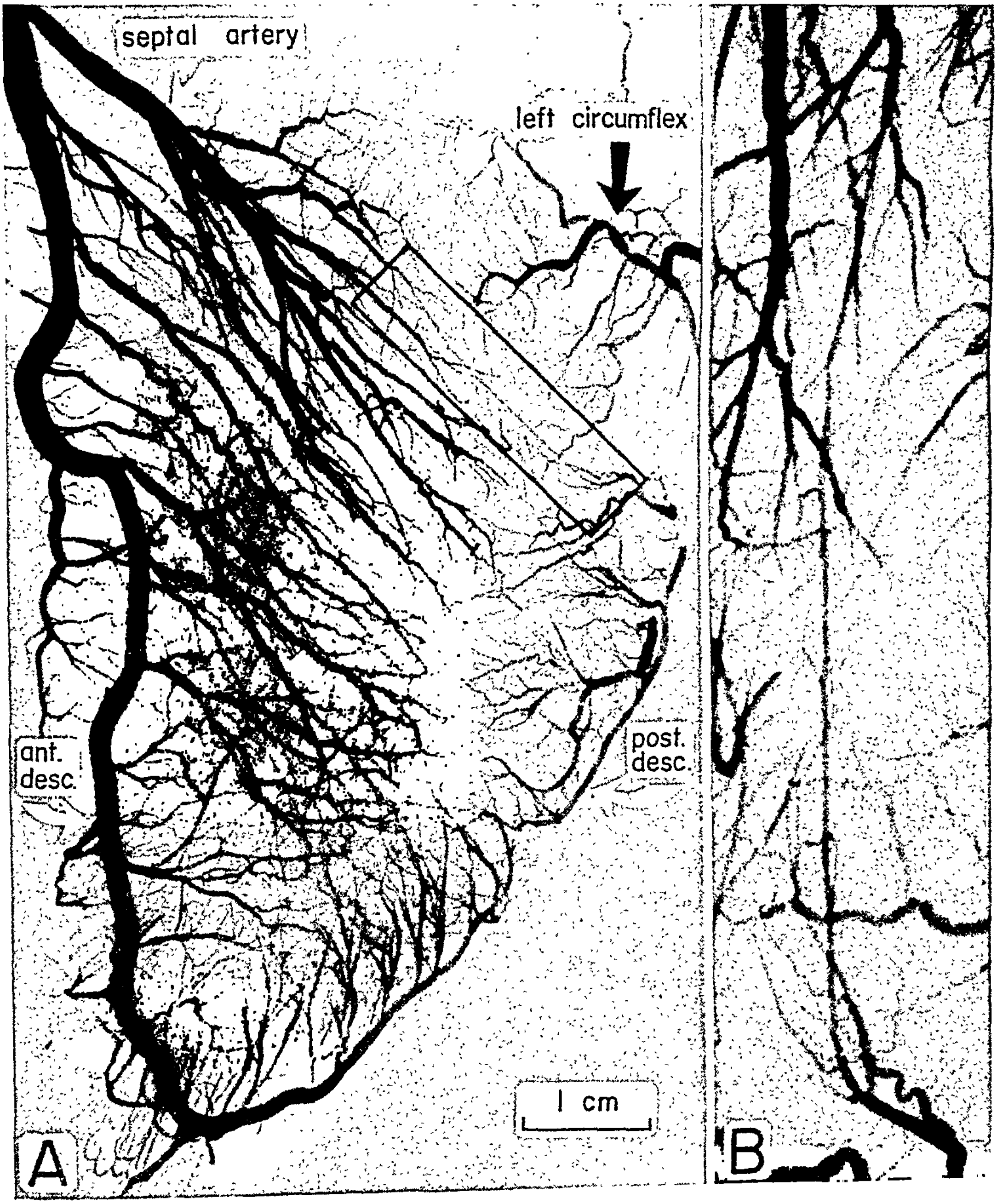

Fig. 15.—Microangiograms of human heart injected through anterior descending coronary artery.

A, Septum in profile view, with branches of anterior descending, posterior descending, and left circumflex arteries, showing a long slender communication between branches of the septal artery and the posterior descending. *B* is a higher magnification of the area marked in *A*.

The manner of junction between adjacent systems or within any one system was much the same in all species studied and in general took one of two forms. The more frequent form appeared to be a direct end-to-end communication of progressively narrowing arterial subdivisions (see Figs. 10 to 14). The apparent point of junction was in general some 40 to 60 micra in diameter as measured in the microangiogram. Smaller connections were seen down to the limit of penetration of contrast mass. The contrast column within these very fine vessels was not always quite continuous. Connections larger than 60 micra were infrequent, a very few were as large as 100 to 150 micra and the largest junction point seen was 200 micra in diameter. Less frequently, the connections were relatively long, slender vessels of uniform diameter and little arborization (see Figs. 10 and 15). These vessels were similar in diameter to the simple junction points but reached a length as great as 2 cm. They connected fine twigs or occasionally larger branches. The connecting vessel frequently widened somewhat near its points of origin and termination (see Fig. 15).

For a rough estimate of the frequency of intersystem communications in the human hearts, counts were made of the numbers of connecting vessels some part of which could be found within circles 1 cm in diameter placed at random along the left border of the injected anterior descending coronary artery. Some 5 to 10 intersystem communications were found for each such area.

DISCUSSION

Microangiography can provide considerably higher magnification and resolution than was needed for these studies. The lower limit in diameter of vessels visualized was determined by the penetration of the contrast mass. We chose a mass which we had found to penetrate consistently into fine arterial subdivisions without entering the capillary bed, and injected it into a single artery or arterial subdivision, leaving all other arteries open to favor flow into interarterial communicating vessels. The direct injection of only one arterial system in each heart also had the advantage of delineating the communicating components of adjacent systems without the dense background of fine vessel filling which characterized the zone of primary injection. The communicating vessels stood out clearly at their terminations in the secondarily filled systems and could be traced back more readily than would have been possible if both systems had been fully injected. For the same reason it was in general easier to trace intersystem communications than communications within the injected system.

In the small hearts—rabbit's and rat's—there were few or no communications of a size demonstrable by the technique employed. Connections that may exist in the order of magnitude of precapillaries and capillaries were not investigated.

Although varying in numbers and distribution in the hearts of the several species examined, the interarterial connecting vessels de[illegible]rated [illegible] pre-ponderantly similar in being either the apparently s[illegible] arborizations of adjacent arterial systems or a relatively straight nonbranching vessel of uniform diameter, varying in length but usually very fine in caliber, of the order of diameter of the terminal arborizations. Morphologic evidence indicates that these vessels as found in normal hearts must present a high resistance to blood flow, so that, despite their presence, the individual arterial branches function virtually as end-arteries, and this is borne out by studies of coronary arterial collateral flow.[14-19] It is clear, however, that there is latent in the normal human heart a definite intercommunicating network, as there is to a varying degree in most of the species studied, which if developed may provide alternative pathways about an occlusion at any location in the coronary arterial system. Enlarged collateral vessels and increased collateral flow following arterial occlusion have been amply demonstrated.[1, 2, 4, 7, 9, 11, 14, 19-21] Examination of the anatomic stages in this development constitutes the next step in the present program of study.

SUMMARY

Stereo-microangiography was applied to a post-mortem study of intercoronary arterial connections in the ventricular walls of normal human hearts and hearts of young adult dogs, pigs, rabbits, and rats. Although the numbers and distribution of connecting vessels differed in the several species studied, the vessels themselves were quite similar and in the main consisted of either (a) the direct junction of the terminal arborization of adjacent arterial systems, ranging in diameter from 20 to 200 micra as measured from the fixed specimens, or (b) a slender nonbranching connecting vessel with a uniform, similar diameter, up to 2 cm. long. Communications were found between branches of the injected artery at various levels within the ventricular wall, but were most frequent near the outer and inner surfaces. Branches of the injected artery communicated with adjacent arterial systems where their terminal arborizations met, i.e., in the ventricular walls, at the apex, in the fat of the atrioventricular sulcus, in the septum, and by way of papillary muscles and muscle bridges across the cavities of the ventricles. Auricular communications were not studied.

It is clear from the patterns of injection that, in spite of the existence of communicating vessels, each injected region was delineated by a border zone of high resistance to the flow of intravascular fluid, and it may be inferred on morphologic grounds alone that no substantial flow through these collateral channels is to be expected immediately, even at the maximal pressure gradient resulting from acute occlusion of an artery feeding one of the bridged systems. However, it is also clear that the normal heart, at least of the larger mammals studied, possesses latent alternative pathways capable of bridging an occlusion at any location in the coronary arterial tree.

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(For Discussion, see page 615)

HANGES IN PULMONARY ARTERY PRESSURE DURING ARDIOPULMONARY BYPASS

n Experimental Study

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*Research Fellow of the American Trudeau Society, Medical Section of the National Tuberculosis Association.

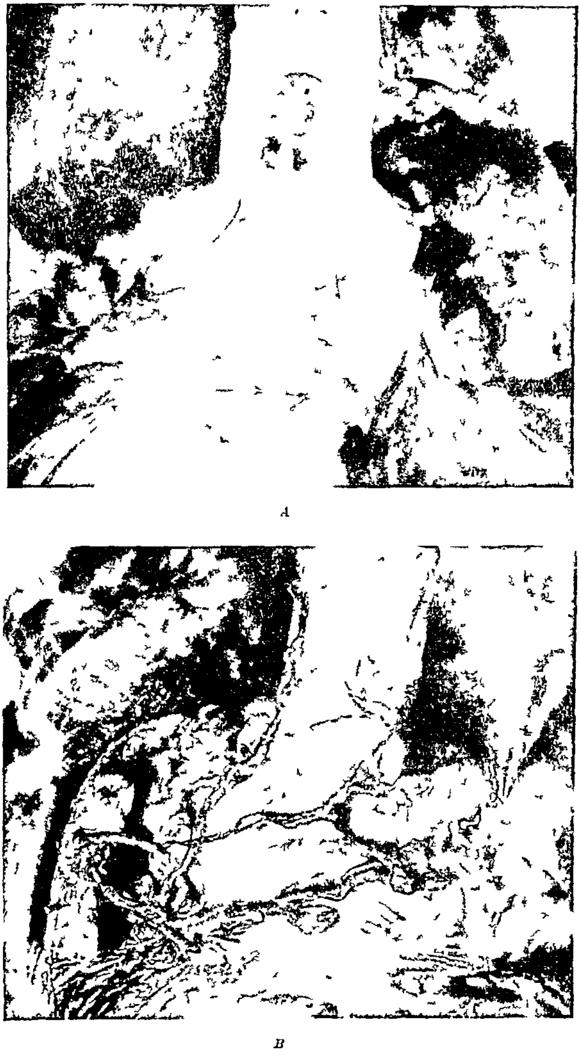

Fig. 1.—A, The bronchial artery of a normal dog showing its limited distribution. B, The extensive bronchial artery distribution in a dog following left pulmonary artery ligation for 10 months.

CHANGES IN PULMONARY ARTERY PRESSURE DURING CARDIOPULMONARY BYPASS

An Experimental Study

James B. Littlefield, M.D. (by invitation), J. Francis Dammann, J., M.D., Phyllis R. Ingram, M.D. (by invitation), and William H. Muller, Jr., M.D., Charlottesville, Va.*

PULMONARY hypertension is a serious complication during cardiopulmonary bypass. The associated pulmonary changes may be transient and of minor importance or result in fatal hemorrhage and edema. This investigation was initiated to determine significant changes in pulmonary artery pressure during cardiopulmonary bypass. A study of these hemodynamic alterations in the lung must consider what influence is exerted by the collateral pulmonary circulation, during heart-lung bypass.

Certain congenital cardiac lesions and chronic pulmonary disease may produce a high bronchial artery flow to the lungs.[1, 2, 3] In pulmonary stenosis, the bronchial artery flow often assumes a major role in collateral pulmonary circulation and may be the primary source of blood to the pulmonary vascular bed.

The dual blood supply to the lungs, through the pulmonary arteries and by way of the bronchial arteries from the systemic circulation, forms numerous collateral communications. The bronchial arteries are of great importance in such a network because they represent the systemic arterial communications between the aorta and the pulmonary vascular bed. These bronchial-pulmonary anastomoses are both precapillary and postcapillary. Precapillary communications were questioned for many years but have been demonstrated in man by Verloop[4] and in the dog, following chronic unilateral pulmonary artery ligation, by Nordenstrom.[5] The presence of postcapillary communications has long been established.[6] Most of the bronchial artery flow from the aorta drains into the left auricle through the pulmonary veins while the remainder enters the systemic venous circulation through the azygos, hemiazygos, or intercostal veins.[7]

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high, decompression through the coronary circulation is inadequate and pulmonary hypertension results In these experiments we have assumed that a pulmonary capillary pressure of 30 mm Hg, which is slightly higher than the colloid osmotic pressure of 25 mm Hg, is capable of producing pulmonary edema

Shedd and associates[17] have investigated the hemodynamic changes in a single lobe of normal and high bronchial artery flow animals with the pulmonary artery and veins occluded and described the hypertension which occurs under these conditions

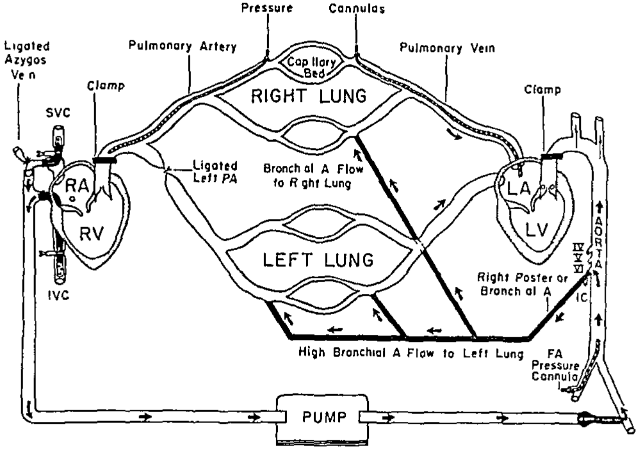

Fig 2—Total Cardiac Bypass With Standstill Experimental Method (pulmonary artery and aorta clamped) The heavy black lines represent the extensive bronchial artery flow which enters the pulmonary vascular bed from the aorta following chronic unilateral pulmonary artery ligation

RESULTS

The pulmonary artery and pulmonary venous pressures were approximately equal during arrest with the pulmonary artery occluded In the dogs with a high bronchial artery flow during total bypass, changes in systemic arterial pressure were reflected in the occluded pulmonary artery, apparently an elevation in systemic arterial pressure is transmitted through the bronchial arteries to the pulmonary vascular bed The highest systolic pulmonary artery pressure demonstrated during partial or total bypass by each animal in the 18 experiments is shown in Fig 3

Before Arrest—Pulmonary hypertension was not a serious problem before elective cardiac arrest One brief period of obstructed venous return to the pump resulted in a pressure elevation to 48 mm Hg An initial transfusion, given as partial bypass was begun, raised the pulmonary artery

In anesthetized normal dogs, Bruner and Schmidt[8] have shown that the bronchial artery flow is usually small (2 to 27 c.c./min.) with a cyclic flow. Bloomer and associates[9] demonstrated that chronic unilateral pulmonary artery ligation in a normal animal, however, may produce a bronchial artery flow in excess of 1,000 c.c. per minute. Several months prior to investigation in this study, we created a high bronchial artery flow in 6 dogs by permanently ligating the left pulmonary artery simulating the increased collateral pulmonary circulation seen in certain patients with congenital heart disease[10] (Fig. 1, *A* and *B*).

We have observed 4 patients during the past 2 years who developed gross pulmonary hemorrhage and edema either during or shortly after cardiopulmonary bypass when elective cardiac arrest with simultaneous aortic and pulmonary artery occlusion was employed.[11] In several other open heart procedures, the pulmonary venous return during cardiotomy was excessive, apparently reflecting the high collateral bronchial artery flow passing through the pulmonary vascular bed.

EXPERIMENTAL METHOD

Eighteen dogs (8 to 20 Kg.) were anesthetized with sodium pentobarbital and positive endotracheal pressure (12-15 cm./water) was maintained by a mechanical respirator. Sixteen experiments were acutely terminated; 2 dogs survived for 18 and 72 hours. A right thoracotomy was employed which extended across the sternum in 2 dogs. The animals were heparinized and then cannulated through the azygos vein, right auricular appendage, and left femoral artery. The femoral and caval cannulae were connected to the bubble oxygenator. The aorta and main pulmonary artery were clamped simultaneously in 10 dogs, the aorta alone in 6, and 2 animals were studied without arrest or cardiotomy. Elective cardiac arrest from 24 to 83 minutes was induced with a 2.5 per cent solution of potassium citrate. The systemic circulation was maintained by the pump-oxygenator, employing perfusion rates from 44 to 160 c.c. per kilogram per minute. Either a right auriculotomy or ventriculotomy was performed. The cardiac septa were intact. The left auricular, pulmonary artery, and distal aortic pressures were recorded and serial lung biopsies obtained (Fig. 2). In 6 normal dogs, a high bronchial artery flow had been created 4½ to 10 months before investigation; these animals were compared with 12 normal controls.

Under these experimental conditions in both animal groups with pulmonary artery and aortic occlusion, the pulmonary vascular bed is isolated. There is no pulmonary artery flow, but the continuous uninterrupted bronchial artery circulation from the aorta below its occlusion perfuses the pulmonary vascular bed. With the pulmonary artery clamped, 65 per cent or more of this collateral flow[8] passes through the open pulmonary veins into the flaccid left auricle. Since the auricular and ventricular septa are intact, the blood has no alternative other than to escape slowly from the left heart through the coronary circulation into the right auricle or become pooled in the pulmonary vascular bed. When the collateral bronchial artery flow is

The diagrams in Fig 5 demonstrate some of the factors which may influence pulmonary artery pressure as shown by this study Decompression of the left auricle lowered the pulmonary artery pressure in both groups of animals

If cardiac activity returns during the arrest period with the pulmonary artery and aorta clamped the pressure is raised by 15 to 20 mm Hg in the pulmonary artery The pressure then falls when elective arrest is again induced

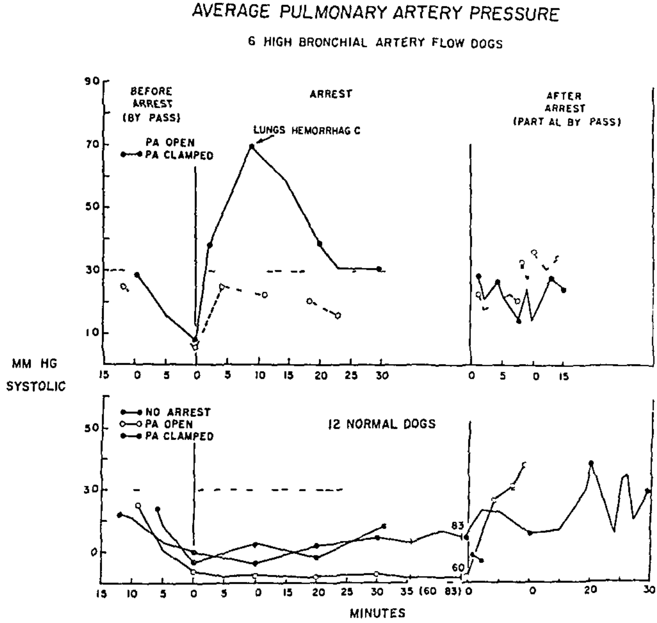

Fig 4—The gradual fall in the curve of the dogs with high bronchial artery flow and pulmonary artery occlusion during arrest, is the result of persistent leakage from the left auricle following periodic decompression After arrest during 15 minutes of partial bypass this same group showed a normal pressure curve the reason for this is not certain

In the dogs with a high bronchial artery flow, and an open pulmonary artery, the pulmonary valve may remain competent, but with distortion of the valve the pressure in the pulmonary artery may fall as much as 15 mm Hg

After Arrest—Pulmonary hypertension was a serious problem in the partial bypass period after arrest in both groups of dogs All of the animals showed intermittent pressure elevations above 30 mm Hg except 1 control dog with pulmonary artery occlusion for 52 minutes and the 2 animals without elective arrest or cardiotomy A pressure of 65 mm Hg was observed in a pressure to 35 mm. Hg. All of these pulmonary hemodynamic changes were intermittent and did not exceed 48 mm. Hg; the highest pressure in the control group was 35 mm. Hg.

Elective Cardiac Arrest.—The average pulmonary artery pressure curve of each group of dogs during partial and total bypass is shown in Fig. 4.

The normal control animals with induced cardiac standstill from 30 to 83 minutes did not show a rise in pulmonary artery pressure above 30 mm. Hg.

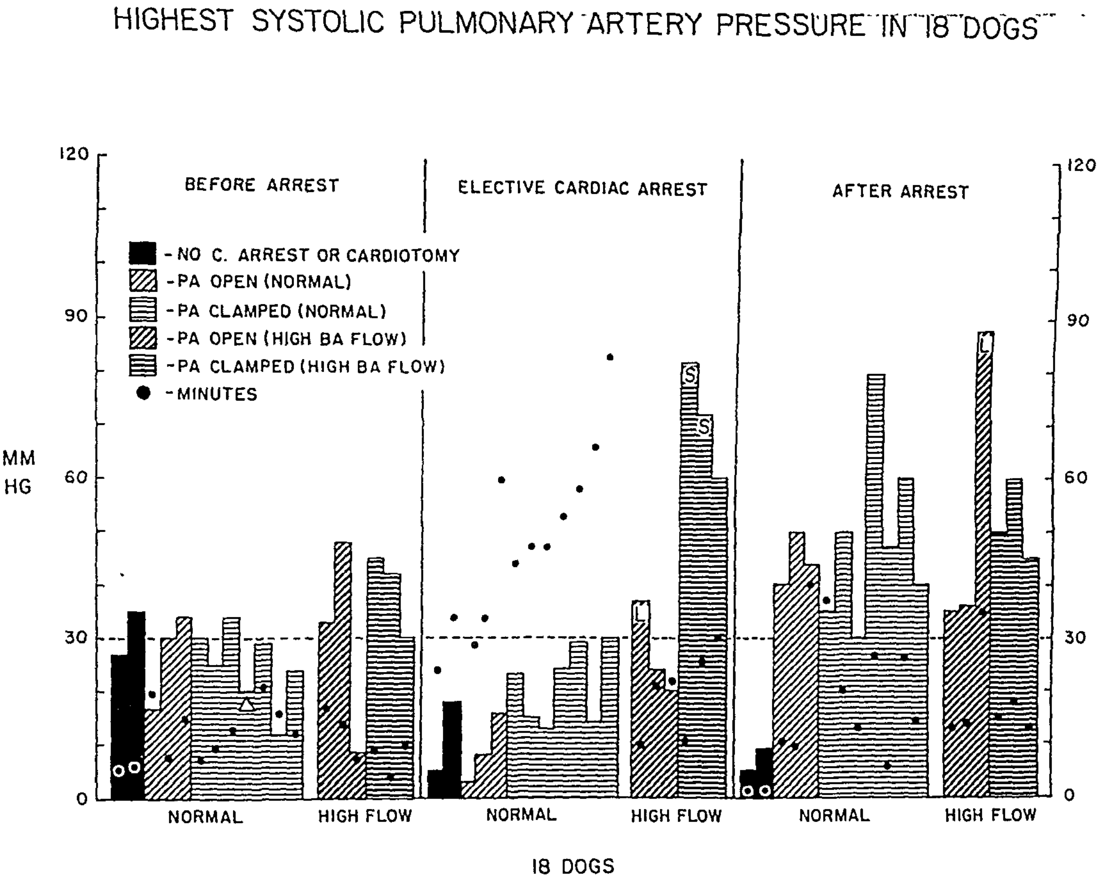

Fig. 3.—A single bar in this graph represents each dog and the bars are arranged in order of the duration of cardiac arrest; this order remains the same in the period before and after arrest.

Δ—no pulmonary artery pressure recorded before arrest.

L—indicates a vasopressor drug effect.

S—sustained pulmonary artery pressure. The rest of the pressures were intermittent.

BA—in the graph legend refers to bronchial artery.

In the dogs with a high bronchial artery flow and an occluded pulmonary artery, the pressure rose rapidly to between 60 and 90 mm. Hg after the induction of cardiac arrest. This sustained pulmonary hypertension was accompanied by a fall in the distal aortic pressure from 120 to 60 mm. Hg; gross hemorrhage and edema with microscopic perivascular, peribronchial, and alveolar hemorrhage occurred within 10 to 30 minutes after simultaneous occlusion of the aorta and pulmonary artery. The pressure remained normal in the pulmonary vascular bed of the animals with a high bronchial artery flow when the pulmonary artery was unclamped.

The diagrams in Fig. 5 demonstrate some of the factors which may influence pulmonary artery pressure as shown by this study. Decompression of the left auricle lowered the pulmonary artery pressure in both groups of animals.

If cardiac activity returns during the arrest period with the pulmonary artery and aorta clamped the pressure is raised by 15 to 20 mm. Hg in the pulmonary artery. The pressure then falls when elective arrest is again induced.

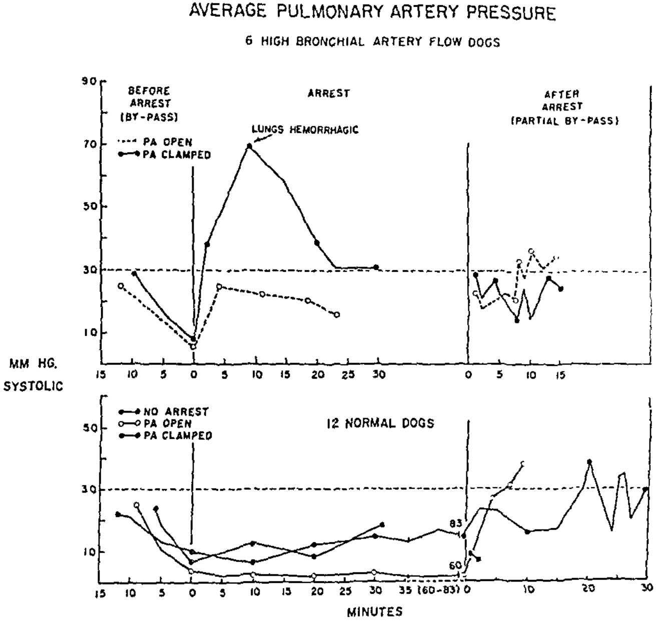

Fig. 4.—The gradual fall in the curve of the dogs with high bronchial artery flow and pulmonary artery occlusion, during arrest, is the result of persistent leakage from the left auricle following periodic decompression. After arrest, during 15 minutes of partial bypass, this same group showed a normal pressure curve; the reason for this is not certain.

In the dogs with a high bronchial artery flow, and an open pulmonary artery, the pulmonary valve may remain competent; but with distortion of the valve the pressure in the pulmonary artery may fall as much as 15 mm. Hg.

After Arrest.—Pulmonary hypertension was a serious problem in the partial bypass period after arrest in both groups of dogs. All of the animals showed intermittent pressure elevations above 30 mm. Hg except 1 control dog with pulmonary artery occlusion for 52 m[illegible] ap[illegible] 2 a[illegible]ls without elective arrest or cardiotomy. A pressu[illegible] normal animal with the pulmonary artery occluded for 47 minutes. During recovery, while on partial bypass, a control dog developed a short period of cardiac arrhythmia accompanied by a sudden rise in pulmonary artery pressure to 85 mm. Hg; this animal's pressure remained elevated for 30 minutes despite continued partial perfusion (Fig. 6). The result of discontinuing cardiopulmonary bypass, before left ventricular recovery, is demonstrated in Fig. 6; there was an immediate rise in pulmonary artery pressure as partial bypass was slowly discontinued.

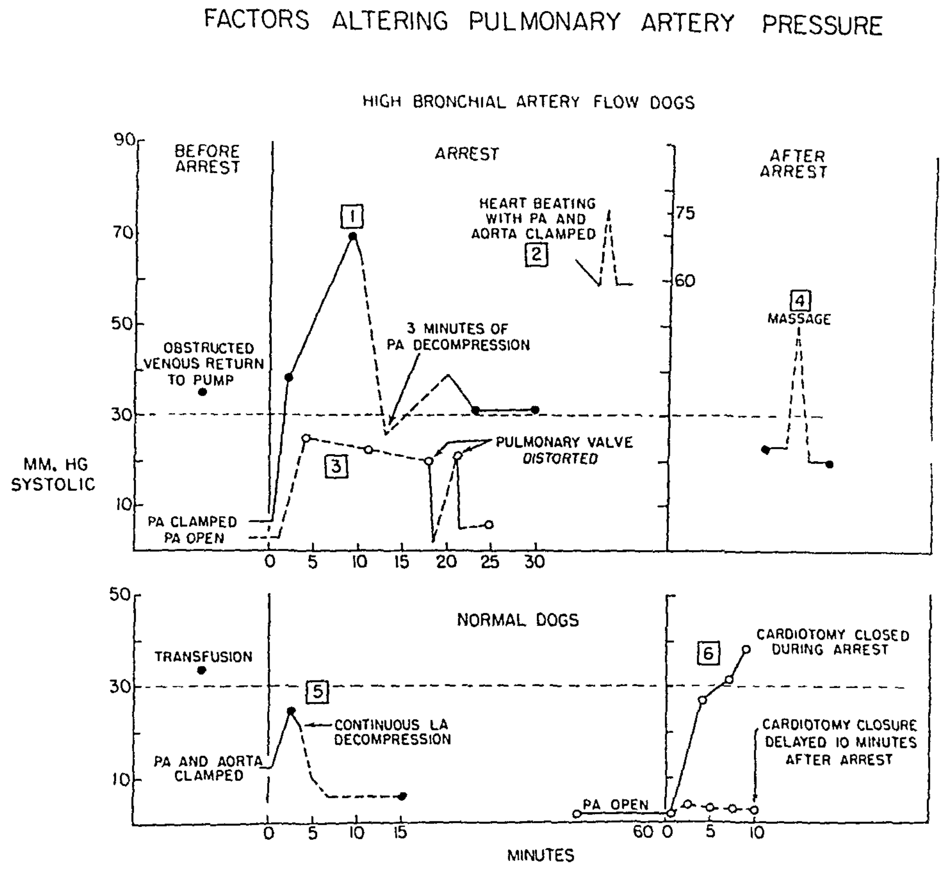

Fig. 5.—Individual factors which alter pulmonary artery pressure. (Normal and high bronchial flow dogs.)

Cardiac massage during recovery may elevate the pulmonary artery pressure as much as 30 mm. Hg (Fig. 5), while delayed cardiotomy closure keeps the pulmonary artery pressure low during the early period after arrest (Fig. 5). Hypervolemia, increased bronchial artery flow, and previous damage to the lungs all contribute to increase pulmonary artery pressure.

Decompression of the left auricle during cardiac recovery prevents pulmonary hypertension.

In Table I the factors contributing to pulmonary hypertension during cardiopulmonary bypass, in this study, are summarized.

The photomicrograph in Fig. 7 shows the typical pathologic lung changes which may result from persistent pulmonary hypertension.

Table I. Factors Contributing to Pulmonary Hypertension During Bypass

BEFORE ARREST	ARREST	AFTER ARREST
1. Transfusion	1. High bronchial artery flow	1. Nondecompressed left auricle
2. Obstructed venous return to pump	2. Nondecompressed left side of heart	2. Delayed recovery of left ventricle (without left auricular decompression)
	3. Occluded pulmonary artery	3. Pump discontinued before left ventricle recovers
	4. Unclamped pulmonary artery with a competent pulmonary valve	4. Hypervolemia
	5. Return of cardiac activity with aorta and pulmonary artery clamped	5. Increased bronchial artery flow
		6. *Arrhythmia*
		7. Massage
		8. Previous pulmonary damage

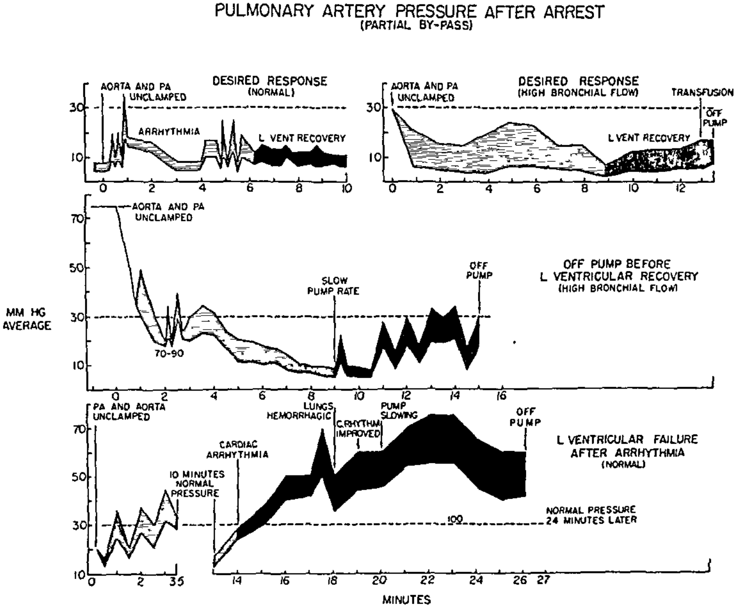

Fig. 6.—The desired pulmonary artery response after arrest is shown at the top. The two lower graphs demonstrate the effect of left ventricular failure. The average systolic aortic pressure is shown by the figures 70-90 (middle) and 100 (lower).

DISCUSSION

This investigation demonstrates several important factors which produce significant changes in pulmonary artery pressure during cardiopulmonary bypass both in normal animals and those with a high bronchial artery flow.

Before arrest, pulmonary hypertension was not a serious problem in any of the dogs. Hypervolemia and a period of obstructed venous return to the pump caused brief, intermittent elevations of pulmonary artery pres

Bronchial artery flow influences pulmonary vascular pressure during elective cardiac arrest. This datum is of clinical as well as academic interest because the high bronchial artery flow present in certain patients with congenital heart disease may raise the pulmonary capillary pressure sufficiently high to cause irreversible hemorrhage and edema. These changes in the lungs may occur during or immediately following open heart surgery. The collateral bronchial artery flow was high in the dogs with chronic, unilateral pulmonary artery ligation; during arrest, when the main pulmonary artery and aorta were simultaneously occluded, fatal hemorrhage and edema resulted within 10 to 30 minutes. The concomitant rise in pulmonary artery pressure and a fall in distal aortic pressure demonstrated by these animals is apparently indicative of the high blood flow which leaves the aorta and enters the pulmonary vascular bed through the enlarged bronchial arteries. These hemorrhagic lung changes were not observed in normal dogs with the pulmonary artery occluded for less than 30 minutes or in the high bronchial artery flow group with the pulmonary artery open. Control animals tolerated standstill with pulmonary artery occlusion for 60 minutes without significant elevations in pulmonary artery pressure.

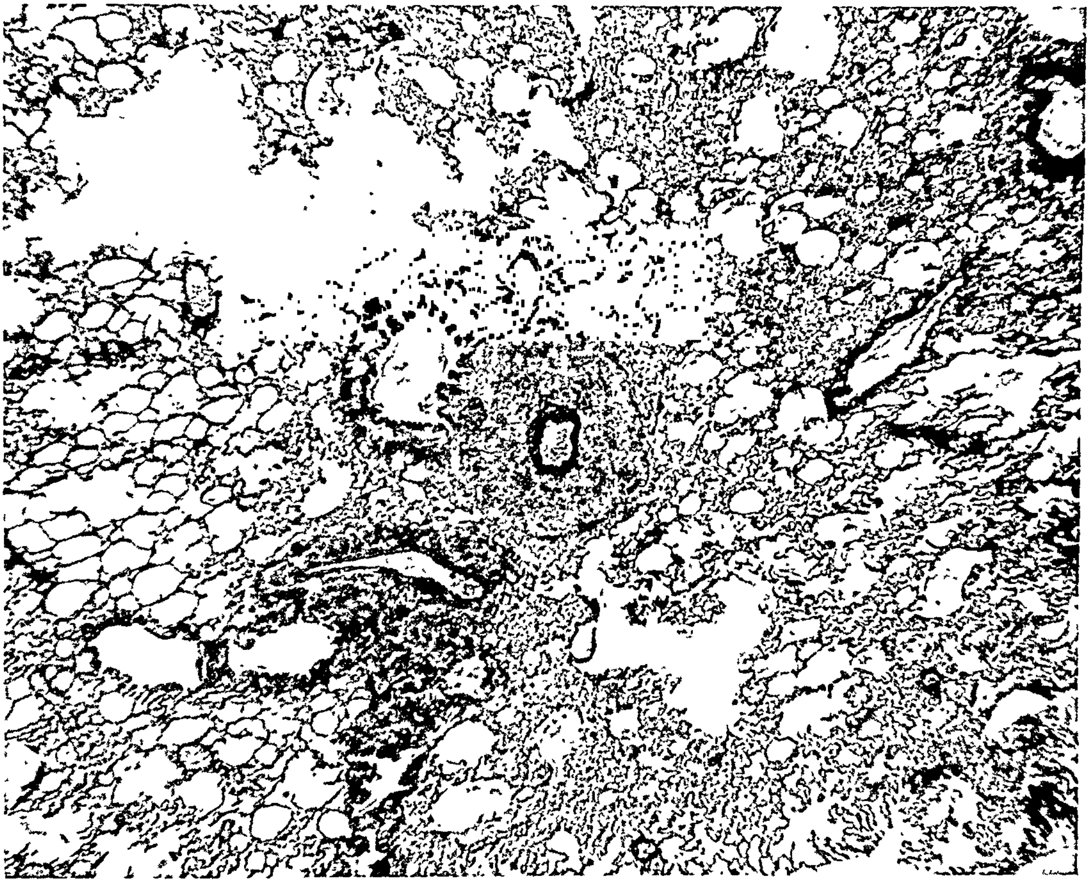

Fig. 7.—Photomicrograph showing the typical perivascular, peribronchial, and alveolar hemorrhage which results from pulmonary hypertension during cardiopulmonary bypass (elastic tissue stain × 15).

An elevated pressure in the pulmonary artery during arrest seems to be directly related to (1) the presence of a high bronchial artery flow, (2) a nondecompressed left side of the heart, (3) the occlusion of the pulmonary artery, (4) an unclamped pulmonary artery with a competent pulmonary valve, and (5) the return of cardiac activity with the aorta and pulmonary artery occluded

Any delay in the return of left ventricular function after elective cardiac arrest is critical This delay may be due to cardiac arrhythmia or left heart failure as the left ventricle attempts to overcome the pump maintained arterial pressure in both groups of dogs The early discontinuance of partial bypass in the recovery period may also result in left heart failure Any delay in left ventricular recovery may result in pulmonary hypertension as the right ventricle recovers early and is not influenced by the resistance of the pump Pulmonary hypertension is a constant threat until the left ventricle functions efficiently

Prolonged and vigorous cardiac massage during the partial bypass phase of cardiac recovery may result in serious damage to the lungs Apparently as the ventricles are compressed the left ventricle has to overcome the pump maintained systemic pressure while the right meets little resistance

In the animal with a high bronchial artery flow hypervolemia and an increased systemic arterial pressure during recovery may increase the bronchial artery flow and in turn raise the pulmonary artery pressure therefore every effort must be made to keep the blood volume and systemic arterial pressure within a low normal range

When elective cardiac arrest exceeded 45 minutes in the control dogs the recovery period was characterized by a significant rise in pulmonary artery pressure above normal, regardless of whether the pulmonary artery had been occluded or open

Pulmonary hypertension following arrest then may be due to (1) failure to decompress the left auricle, especially if left ventricular recovery is delayed, (2) discontinued partial perfusion before the left ventricle recovers, (3) hypervolemia, (4) an increased bronchial artery flow, (5) cardiac arrhythmia, (6) cardiac masage, and (7) previous pulmonary damage

Several precautions must be observed to avoid pulmonary hypertension during cardiopulmonary bypass The left auricle should be constantly decompressed, this is the most important single factor in preventing pulmonary hypertension The pulmonary artery must be left open After the aorta is unclamped, partial bypass should be continued until the left ventricle has recovered Delayed cardiotomy closure after arrest may be indicated, as demonstrated in these studies, however, each patient must be considered individually and the appropriate treatment should depend upon the central venous and left auricular pressure response A normal systemic arterial pressure with a normal or reduced blood volume should be maintained An uninterrupted venous return to the pump m[illegible] assur[illegible] t all times

These studies indicate that short periods of elevated pulmonary artery pressure are of little importance, while repeated or prolonged pulmonary hypertension may cause pathologic pulmonary changes at any time during cardiopulmonary bypass.

SUMMARY AND CONCLUSIONS

Several factors have been presented which alter pulmonary artery pressure during cardiopulmonary bypass in dogs with normal and high bronchial artery flow. Short periods of elevated pulmonary artery pressure may be well tolerated while repeated or sustained pulmonary hypertension may produce pathologic pulmonary changes.

Throughout cardiopulmonary bypass pulmonary hypertension may be avoided by:

1. Left auricular decompression, which is the most important single factor in preventing the development of pulmonary hypertension.
2. An unoccluded pulmonary artery.
3. Partial bypass after the aorta is unclamped until the left ventricle has recovered.
4. Delayed cardiotomy closure following arrest as shown in these studies. However, clinically each patient must be treated individually depending upon the left auricular and central venous pressure response.
5. The maintenance of a normal systemic arterial pressure with a normal or reduced blood volume.
6. The assurance of an uninterrupted venous return to the pump.

We wish to express our appreciation to Mary Elizabeth Garrard and Boyd Perry for their technical assistance.

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Discussion

(Papers by Ross [page 534], Cordell [page 543], Neaton [page 549], Robinson [page 555], Roe [page 563], Austen [page 571], Bellman [page 584], Littlefield [page 604] and Their Associates)

DR. SANFORD LEEDS, San Francisco, Calif.—I should like to discuss Paper No. 20 by Dr. Cordell. My associates and I at the experimental surgery laboratory of the Mount Zion Hospital in San Francisco have studied the flow of lymph from the right lymphatic duct and the thoracic duct before and after raising the pressure in the left atrium to simulate acute mitral stenosis.

A total of 66 experiments have been performed since December, 1956. The first group of experiments were to establish a method of draining the lymph from the right lymphatic ducts. This method consists of creating a chamber within the external jugular vein for the collection of lymph from the right ducts.

(slide) This shows the plastic tube in the external jugular vein. The lymph from the right ducts flows into this chamber. The rate of flow and pressure are measured and the specimens are collected for laboratory studies.

(slide) In preliminary studies in which the method described by Drinker and Warren was used, only 4 successful studies in 11 experiments were obtained (36 per cent). By using the method described, successful studies were obtained in 19 of 24 experiments ([illegible] per cent). As experience is gained with this method, an even higher percentage is anticipated. This method has the additional advantage over Drinker's in that the accumulated flow of the right lymphatic ducts is measured rather than just the flow of a single cannulated duct.

Time does not permit a complete report of our results. These will be presented at the San Francisco meeting of the American College of Chest Physicians and the Cardiologic Congress in Brussels.

The method for raising the pressure in the left atrium while measuring the flow of lymph from the right lymphatic duct and the thoracic duct is illustrated in the next two slides.

(slide) The balloon is placed in the left atrium indicated by the dotted area, a catheter connected to a manometer is placed in the left atrium so that the pressure is elevated to about 30 mm. Hg in order to simulate acute mitral stenosis.

(slide) This Kodachrome shows the congested appearance of the lung, which may become bright red in color. The surface becomes moist and actually red blood cells are loosened from the surface as well as fluid.

In general, the flow is increased in both the right lymphatic duct and the thoracic duct. The time relationships indicated that there is a period of ½ to 2½ hours required for lymph to accumulate in the lung before an increase in flow develops. The pressure in the left atrium was elevated to 30 mm. Hg or more. Further experiments are in progress to determine how much of the thoracic duct flow is from the lungs and how much from below the diaphragm.

DR. EARLE B. KAY, Cleveland, Ohio.—I would like to congratulate Dr. Roe and his associates upon their excellent basic work in the development of prosthetic valves. With the extracorporeal circulation, by means of a pump oxygenator, acquired valvular disease of the mitral valve, at least, can be surgically corrected in the majority of patients. Patients with aortic valvular disease, particularly aortic regurgitation, have so far not benefited to the same degree, however. The problem has been largely twofold. To begin with, the aortic valve in many such patients is so destroyed that it appeared initially that

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SUMMARY AND CONCLUSIONS

Several factors have been presented which alter pulmonary artery pressure during cardiopulmonary bypass in dogs with normal and high bronchial artery flow. Short periods of elevated pulmonary artery pressure may be well tolerated while repeated or sustained pulmonary hypertension may produce pathologic pulmonary changes.

Throughout cardiopulmonary bypass pulmonary hypertension may be avoided by:

1. Left auricular decompression, which is the most important single factor in preventing the development of pulmonary hypertension.
2. An unoccluded pulmonary artery.
3. Partial bypass after the aorta is unclamped until the left ventricle has recovered.
4. Delayed cardiotomy closure following arrest as shown in these studies. However, clinically each patient must be treated individually depending upon the left auricular and central venous pressure response.
5. The maintenance of a normal systemic arterial pressure with a normal or reduced blood volume.
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10. Littlefield, J. B., Ingram, P. R., Blanton, F. S., Jr., Dammann, J. F., Jr., and Muller, W. H., Jr.: Bronchial Artery, Left Auricular Blood Flow: Its Relation to Pulmonary Damage in Extracorporeal Circulation, Surg. Forum 8: 428-432, 1958.

great difficulty of preventing embolization (if our experience with intrinsic mitral baffles is any guide), we have given attention primarily to the establishment of a prosthetic aortic takeoff at the apex of the left ventricle This prosthetic aorta contains the valve and is anastomosed end to side to the thoracic aorta just above the diaphragm The concept is of course not original with us It has had many advocates including Donovan, Hufnagel, Bailey and, especially, Sarnoff Once a satisfactory new outflow tract without gradient is provided, certainly the natural tract containing the aortic stenosis would cease to have significant function In the event of aortic insufficiency, surgical obstruction of the damaged aortic valve should not be difficult However, these attractive adventures in replacement are not realities and will not be available within the life span of many of our patients who are now symptomatic from aortic stenosis I will address myself to the available corrective surgical techniques at another point in the program

We must recognize the fine work and attempts at objectivity by Drs Austen, Shaw, Thurlbeck, and Scannell in studying the hemodynamics of aortic stenosis and its correction However, when one uses static flow states to study valves that operate under pulsatile conditions, when the time of opening and the time of closure of leaflets are not taken into consideration, when linear relationships between valve orifices, pressure, and flow are assumed when the curves are exponential, and finally when this group assumes that their corrective techniques are the only possible or at least the best it is possible to come to erroneous conclusions I do sincerely congratulate these capable men on their earnest effort at objectivity but urge them to use something like the McMillan pulsator for their studies This may alter their corrective techniques, their results and their clinical approach At least it has done so for us

The conclusion that open operations are necessary to avoid embolus is simply not consistent with our experience This experience with calcific aortic stenosis in adults will be reviewed tomorrow In the first 100 consecutive operations, death from embolus occurred only in the first patient, and this was the only case where head vessel occlusion was not used as a protective technique

In short, I rise to object respectfully to the application of stable flow studies to a pulsatile flow situation We use the McMillan pulsator for these studies and our conclusions are different

DR THOMAS C MOORE, Indianapolis, Ind —I wish to congratulate Dr Robinson and his associates on their interesting study relative to the problem of pulmonary artery replacement and bypass Although we have had no direct experience with experimental pulmonary artery replacement in our laboratory at the Indiana University Medical Center, we have had considerable experience with vascular replacement in similar critical areas during the past several years Some of our observations may be pertinent to their experiences with pulmonary artery replacement

Our investigations have been carried out on dogs and have concerned the problems of vena cava replacement and of replacement and bypass of small arteries, including the carotid, femoral, and coronary arteries We have found fresh autogenous arterial grafts to be quite superior to either freeze dried or alcohol preserved arterial homografts in small artery replacement Furthermore, we have found the use of grafts of fresh autogenous aorta to be the most successful in the replacement of resected segments of superior vena cava The autogenous aorta was obtained by resecting a portion of aorta and reestablishing aortic continuity by means of an aortic homograft This type of superior vena cava replacement was carried out in 33 animals In all 33, studied up to 1 year after placement, the vena cava replacement had repaired, patent and free of narrowing and thrombosis formation In both these critical areas of vascular replacement, the autograft was shown to be clearly superior to the homograft

With respect to the problem of pulmonary artery replacement, I should like to suggest the experimental use of both fresh autogenous systemic artery and fresh autogenous vein It is likely that both these types of grafts would prove to be superior to the preserved homograft for pulmonary artery replacement nothing short of total valvular replacement would suffice. We have found that a variety of techniques may be necessary, depending upon the variation in the presenting pathologic lesions. The addition of valve substance in the form of compressed Ivalon to the shrunken cusp may in many instances correct the regurgitation. Either one or two cusps have had the addition of this plastic material secured on the aortic side with complete relief of the regurgitation.

The second problem has been the proper method by which the aortic valve could be exposed for a sufficiently long period to allow definitive surgical correction without the deleterious effects of myocardial anoxia. Aortic occlusion with and without cardioplegic drugs will allow successful exposure of the valve if only a short time is required. In our experience, retrograde coronary sinus perfusion has not increased either the safety or length of time that the aortic valve can be exposed without deleterious effect upon the myocardium. For the past several years, we have been attempting to develop a suitable technique for direct coronary perfusion. Such a technique, requiring special cannulae, was recently successfully used in the correction of aortic regurgitation in a 30-year-old white man. The coronary ostiae were cannulated through the aortic incision with a flow rate of 250 c.c. per minute. The myocardium was kept well oxygenated for the 47 minutes required for the correction of the aortic regurgitation, which entailed the plastic correction of the valve cusps as well as the addition of valvular substances to allow cusp approximation. (One-minute movie strip demonstrating the procedure.)

DR. ROBERT TROUT, Philadelphia, Pa.—We have been pursuing the problem of valvular prosthesis for some 14 months at Presbyterian Hospital in Philadelphia. We have been working on the theory utilizing an in vitro biologic membrane, that is autogenous or homologous, for expediting the production of pseudoepithelium on material we felt was suitable for the fabrication of the valve. The material now being used is a Dacron mesh, nylon having been discarded. We have been able to initiate and to perpetuate for some 9 months now, two basic tissue cultures of canine fibroblasts; one of these is an embryonic culture taken originally from the tendo-Achilles of embryonic pups, and the second from the rectus fascia of the adult mongrel dog.

This slide shows adult fibroblasts enmeshing the Dacron fibers as it forms a fine smooth covering.

This slide illustrates embryonic tissue from our culture. You will note that the cells are somewhat different in shape; we have not yet been able to evaluate the significance of this, if indeed there is any.

This slide shows a tissue-culture covered tag; this is not a valve but merely a tag of cloth which has been previously coated and placed in the thoracic aorta to test the reaction. It is noted that the cells are viable. This one was in place for some 2 weeks. We now have in place such tags for up to 3 months, having produced aortic insufficiency to ensure flaplike motion of the material.

(slide) Here we see the tag of embryonic tissue 2 weeks following implantation; above you can see the aortic wall. This is the tip of the tag lying free in the aorta with additional fibroblasts being laid down by the host.

This slide shows the design of the valve. It is a single cusp type of valve which is sutured to the fibromuscular base of the two coronary cusps, following resection of the diseased valve, then sutured up the side of the aorta as you can see. This is done through an incision in the base of the aorta over the posterior cusp. This has worked very nicely in autopsy specimens and the valve has been found to be efficient when checked on the pulse duplicator. We are now going ahead with autogenous tissue and valve implantations in animals.

DR. DWIGHT E. HARKEN, Boston, Mass.—We congratulate Dr. Roe and his colleagues on their modest presentation of ingenious work on prosthetic valves. In attendance here are the men who most clearly sense the problems and are most likely to offer solutions to the problems of irreparably damaged valves.

Our efforts have been stimulated by Dr. Vannevar Bush who has designed and fashioned a variety of prosthetic aortic valves for us. Impressed with the difficulty of excision and replacement of the extensively damaged aortic valve and recognizing the great difficulty of preventing embolization (if our experience with intrinsic mitral baffles is any guide), we have given attention primarily to the establishment of a prosthetic aortic takeoff at the apex of the left ventricle This prosthetic aorta contains the valve and is anastomosed end to side to the thoracic aorta just above the diaphragm The concept is of course not original with us It has had many advocates including Donovan, Hufnagel, Bailey and, especially, Sarnoff Once a satisfactory new outflow tract without gradient is provided, certainly the natural tract containing the aortic stenosis would cease to have significant function In the event of aortic insufficiency, surgical obstruction of the damaged aortic valve should not be difficult However, these attractive adventures in replacement are not realities and will not be available within the life span of many of our patients who are now symptomatic from aortic stenosis I will address myself to the available corrective surgical techniques at another point in the program

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DR. RALPH D. ALLEY, Albany, N. Y.—Dr. Littlefield has very nicely covered the significance of bronchial collateral flow in open heart surgery. The cardiac defects accompanied by increased bronchial collateral flow are those defects in which pulmonary stenosis is a component. I arise to point out that bronchial arterial expansion is also seen in chronic pulmonary disease states and, therefore, the occasional patient with a congenital cardiac defect without pulmonary stenosis as a component but who has even a small area of chronic pulmonary disease, may present a problem because of increased bronchial collateral flow.

In support of this point, I wish to present a case which illustrates acquired expansion of the bronchial arterial collaterals in perhaps its most exaggerated form. Unequivocal evidence of a massive left-to-right shunt between the bronchial and pulmonary arteries was obtained and will be shown.

This slide shows the x-ray of the chest of a 53-year-old woman with unilateral suppurative disease of 43 years' duration. The changes demonstrating a destroyed left lung require no interpretation.

This slide is of an angiocardiogram showing filling of the right pulmonary artery but no filling of the pulmonary artery on the diseased side. This phenomenon has been previously documented in similar cases many times, especially by Dr. Steinberg and Dr. Dotter. We were led, however, to do an aortogram on this patient because, despite the absence of systemic hypertension or valvular disease, she had a pronounced left ventricular hypertrophy on the electrocardiogram.

(slide) This is the one-second film of the aortogram showing a mass of huge tortuous bronchial arteries which preferentially opacify in competition with the aorta which is faintly seen.

(slide) On the 3-second aortogram film, you see retrograde filling of the left pulmonary artery via the bronchial arterial communications.

(slide) This shows a bronchovascular corrosion cast of the pneumonectomy specimen. The pulmonary artery and collaterals are in red dye, the pulmonary veins in blue, and the bronchi in yellow. The bronchial and pulmonary arterial systems filled through an injection of the pulmonary artery. The injection of the bronchi demonstrates the presence of multiple lung abscesses and bronchiectasis.

(slide) This shows a close-up view of the lower end of the cast. These loops and plexiform clusters represent myriads of 1 to 2 mm. communications between the bronchial and pulmonary artery systems.

On cardiac catheterization this patient showed a step-up of 2 volumes per cent in oxygen content in passing the catheter from the right ventricle into the main pulmonary artery. The left pulmonary artery could not be entered. The right heart output was normal. Measurement of the left heart output by the dye method was attempted but showed such massive and early recirculation that it could not be calculated.

It is unlikely that patients with congenital heart disease will be operated upon with extensive pulmonary disease unrecognized, but this phenomenon can be seen in areas of bronchiectasis that might be overlooked, and should be borne in mind.

DR. ROBERT KLOPSTOCK, Brooklyn, N. Y.—Dr. Nealon and Dr. Gibbon have concluded that the patient's position does not affect the ventilation required to maintain normal carbon dioxide levels in arterial blood. Drs. Arthur Siebens, Austin Grant, and I have also been interested in the effects of the patient's position on respiration and we wish to ask one question of Dr. Nealon and to make one observation pertaining to the effects of position in patients with pneumonectomies.

It is well known that when a patient is turned onto his side the diaphragm on that side is pushed up by the weight of the viscera, the rib cage is compressed by the weight of the body, and the mediastinum shifts down, the result of these changes being a reduced end-expiratory volume in the inferior lung. The volume of the superior lung, on the other hand, is increased, for the upper diaphragm is pulled down and the costal interspaces expand. Under these circumstances, one might well anticipate that the force required to ventilate each lung would be increased. This force in the inferior lung would need to overcome the additional weight of mediastinum and viscera, and in the superior lung would need to overcome an elastic resistance which was abnormally increased because of the lung's greater volume. We would like to ask, therefore, whether Dr. Nealon compared the pressures required to maintain equal ventilation in these two positions. Any differences would probably be of little consequence in a pressure-cycled mechanical respirator, but might be of some consequence in a volume-cycled respirator or during manually administered respiration. Our question really becomes, How does the total work of breathing compare in these two positions?

The observation we wish to present concerns the effects of position in patients with pneumonectomies. One might think that, because the effects of positional changes on the lung are so considerable, the patient with one lung might breathe to better advantage in one position than in another. Eight patients with pneumonectomies were studied in supine, right lateral, left lateral, and sitting positions. Oxygen consumption, ventilation, and gas composition of arterial blood were measured. It was found that the patient with a pneumonectomy does not exhibit a typical pattern of change in alveolar-arterial partial pressure gradient, physiologic dead space, or alveolar ventilation when variously positioned. Although some patients did show significant changes in one aspect of function or another, these were exceptional. In most instances, ventilation, oxygen consumption, and the ventilatory equivalent were least with the patient supine. It was concluded that, with few exceptions, the lateral positions offered these patients few advantages, in terms of respiration, over the supine position.

DR. R. MAURICE HOOD, Oakland, Calif.—I should like to thank you for the privilege of the floor. Dr. William Snow Miller studied pulmonary circulation in dogs in 1926, with particular regard to bronchial artery circulation. We have been interested in bronchial artery circulation for another purpose entirely. It has come to our attention that the bronchial artery circulation of dogs, as set forth many years ago by Miller, is not the same as in human beings. At least this is true in the normal animal and the normal human being without pulmonary disease. The bronchial artery in the human being supplies the parenchyma of the lung in contrast to the dog, where it supplies only the bronchial tree and stops at the level of the respiratory bronchial. In the normal individual, there is only a limited communication between the pulmonary artery and the bronchial artery. The dog's communications are quite gross. Therefore, I wonder about the total applicability of this study to human beings.

DR. FOREST D. DODRILL, Detroit, Mich.—I should like to comment briefly on the paper of Dr. Roe and to compliment him on his basic and fundamental contribution, a subject which I have no doubt will be of increasing importance as time goes on. We have had a similar tricuspid valve for about 3 years, but the difficulty with it seems to have been that we could not place it in the proper position, namely, below the coronary ostia. We have therefore modified it in order that this may be accomplished.

(slide) This is similar to Dr. Roe's valve and is made of silicone and is very stable.

This slide shows a modification of the valve. The artificial coronary arteries are shown, and you see that the coronary arteries come off in their normal position as an integral part of the valve.

This slide is a diagram of how the valve is put in. This is done using the cardiac bypass, the section of the aorta is excised, the valve is sutured in place and the artificial coronary arteries are anastomosed to the natural coronary arteries.

I might say that we have not had any long-term survivors with this type of valve. I think from the standpoint of these valves there are three important points. One is the construction of the valve so that it functions properly. The second point is the lasting qualities of the substances which we use, and I might add that there are a great number of chemicals which are rapidly coming on to the market, and it is hoped that some of these will be even more applicable for use. Third, is the absorption factor. The silicone material which we use, and which others use, has a water absorption of 0.5 of 1 per cent, so that we think it is helpful if these valves are soaked in heparin solution for 24 or 48 hours before they are inserted, so that a small quantity of heparin is gradually released from the valve as time goes on. Finally, if the clotting difficulties are unsurmountable, it should be kept in mind that it is not inconceivable that patients who have artificial valves inserted could be kept on continuous anticoagulant therapy.

DR. KEITH REEMTSMA, New Orleans, La.—I appreciate the privilege of the floor, and I should like to comment on the papers dealing with pulmonary artery pressures and blood flow during extracorporeal circulation.

The group working with Dr. Creech at Tulane has been interested in pulmonary complications following open heart procedures. In particular, the problem of diffusion, using the carbon monoxide method, has been under investigation. Determinations in 4 patients before and at various intervals after open heart procedures showed impairment of diffusion postoperatively, and 2 of the patients demonstrated persistent impairment 2 to 4 weeks after operation.

The excellent experimental studies presented today suggest a mechanism which may be involved in these pulmonary complications of extracorporeal circulation.

DR. THOMAS F. NEALON, JR., Philadelphia, Pa.—I would like to answer Dr. Klopstock's question concerning the pressure necessary to provide ventilation for the patients in the supine and lateral position.

In 5 cases, essentially the same volume of ventilation was necessary in the supine and the lateral positions. In 3 of these, exactly the same pressure which was adequate in the supine position was also adequate in the lateral position, and we were quite surprised to find that, in the other 2 instances, less pressure was needed to provide the same ventilation when the patient was turned.

DR. W. GERALD AUSTEN, Boston, Mass.—I would like to answer Dr. Harken's question. We certainly agree with Dr. Harken that our experimental situation is not the same as in life. However, our data does correlate very well with the clinical situation. Moreover, it is the only way we have been able to quantitate regurgitation accurately; the accurate evaluation of the degree of regurgitation in postoperative patients has been regrettably neglected thus far. Finally, we have also employed a pulsatile system, which seems to correlate well with our steady flow data.

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In Memoriam

RUDOLPH MATAS (1860-1957)

On September 23, 1957, the world lost one of the most eminent pioneer thoracic and vascular surgeons by the death of Rudolph Matas. Dr. Matas was a founder member of The American Association for Thoracic Surgery and its president in 1921. Although Dr. Matas will be remembered largely for his work in vascular surgery, particularly in the field of aneurysms, he will also be remembered for his original investigative work in thoracic surgery, being one of the first to emphasize the disastrous effects of acute surgical pneumothorax. At the meeting of the Southern Surgical and Gynecological Association (now the Southern Surgical Association) in 1899, Dr. Matas reported on intralaryngeal insufflation (Intralaryngeal Insufflation for the Relief of Acute Surgical Pneumothorax. Its History and Methods With a Description of the Latest Devices for This Purpose, J. A. M. A. 34: 1371, June 2, 1900) and stated: "Until the danger of seriously interfering with respiratory functions by introducing acute collapse of the lung is thoroughly eliminated or is reduced to a safe minimum, an analogy between the pleura and the peritoneum from the surgical point of view will never exist." In May, 1898, he discussed surgery of the chest and emphasized the value of the Fell-O'Dwyer apparatus as a method of preventing and overcoming the effects of acute traumatic thorax in thoracic operations and, in a presentation before the American Surgical Association in May, 1901 (Artificial Respiration by Direct Intralaryngeal Intubation With Modified O'Dwyer Tube and a New Graduated Air Pump: Its Application to Medical and Surgical Practice, Tr. Am. S. A. 19: 392, 1901), he reported the results of animal experimental investigations, which he and Dr. John Smyth performed, demonstrating that a pump employing negative as well as positive pressure was actually harmful. He stated: "After demonstrating to our satisfaction that the double inspiratory and expiratory pump was not a practical appliance for artificial

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Read at the Executive Session of the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 17, 1958.

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respiration, we abandoned the aspirating cylinder entirely in our work a utilized a single insufflating cylinder on the O’Dwyer principle and found perfectly reliable and made it the basis for our practical clinical respirato machine.”

Dr. Matas was born in Bonnet Carre, Louisiana, a short distance fro New Orleans, on September 12, 1860. His father and mother, who were nativ of the Spanish province of Catalonia, returned to Spain shortly after youn Rudolph’s birth. In 1867, they left Barcelona and returned to the Unit States, where Dr. Matas had his preliminary education in New Orleans and i Matamoros, Mexico. He enrolled in the Medical School of the University Louisiana (now Tulane University) in the fall of 1877 and received his Docto of Medicine degree in March, 1880. While still an undergraduate medical student, he won competitively a two-year internship at the Charity Hospital an also, while a medical student, was appointed to the Havana Yellow Fever Commission as an interpreter and laboratory assistant. He went with the Commission to Cuba in 1879. In 1880, while an intern at the Charity Hospital, h assisted at the first laparotomy performed in that institution under Listeria ritual, including the use of carbolic acid spray. In 1882, shortly after graduation, he went to Mier, Mexico, to treat an epidemic of yellow fever in that city In 1886, he was appointed Demonstrator of Anatomy at Tulane University, holding this position until he was appointed Professor of Surgery and Chairman o the Department of Surgery in 1894. On his retirement in 1927, he became Professor of Surgery Emeritus.

Dr. Matas’s first endoaneurysmorrhaphy was performed on May 16, 1888 when, after attempting to control an aneurysm by proximal and distal ligation he found there was bleeding through many collaterals which he was able t demonstrate by opening the aneurysm. Following removal of the tourniquet he saw that blood was coming from various orifices and reasoned that suturing th orifices might control the bleeding, which it did; thus, the operation of endoaneurysmorrhaphy was accomplished. In commenting on this operation whe he saw the well patient 10 years later, he stated: “At the time this operatio was performed, I had no precedence to guide me. The only work that had bee done was that of Glueck, published in Langenbeck’s Archives, in which he detailed nineteen experiments in the suture of arteries which had failed to a grea extent in spite of the ingenious methods that he devised. The exigencies o the case, however, made it necessary that hemostasis should be obtained, an the occlusion by suture appeared to be so easy and plain that it seemed to m that any surgeon similarly situated would instinctively have adopted this simpl way of getting out of the difficulty.” His experience in the treatment o aneurysms was enormous because of the great wealth of material at the Charity Hospital, both in spontaneously occurring and traumatic aneurysms. He also did considerable experimental investigative work, and he and Dr. Carroll Allen devised an aluminum band which permitted temporary occlusion of vessels without injury to them. Before the American Surgical Association in St. Louis on May 2, 1940, Dr. Matas reported a total of 620 operations for aneurysms, of which 101 had been treated by the suture method. Another contribution which Dr. Matas made to vascular surgery was elaboration of the hyperemic test to determine the adequacy of collateral circulation following obliteration of the vessel (Test to Determine the Efficiency of the Collateral Circulation Before Attemping Permanent Occlusion of the Great Surgical Artery, Ann. Surg. 52: 126, 1910).

He did more than anyone else to elucidate our concept of the production of elephantiasis and its prevention. His first discussion on this subject was before the Southern Surgical Association in 1911, and his extensive report in 1913 (The Surgical Treatment of Elephantiasis and Elephantoid States Dependent Upon Chronic Obstruction of Lymphatic and Venous Channels, Am. J. Trop. Dis. and Prevent. Med. 1: 60, 1913) is a classic today. Dr. Matas also performed the first Kondoleon operation in the Western Hemisphere. The original communication by Kondoleon appeared in the *Zentralblatt für Chirurgie* on July 27, 1912, and Dr. Matas's first Kondoleon operation was performed on October 20, 1912.

Dr. Matas had tremendous interest in the increasing incidence of thromboembolism. In a report before the International Society of Surgery in Warsaw in July, 1929, and in the Donald Balfour Lecture at the University of Toronto on April 5, 1932, he emphasized that this was a disease of modern surgery.

Dr. Matas is known for several "firsts." He was the first person to use intravenous saline in a surgical patient. He was also one of the first to advocate gastric drainage and, in 1924, emphasized the value of the indwelling Jutte tube, introduced through the nose. Dr. Matas was one of the first to use spinal anesthesia and on November 18, 1899, he first used cocaine. He did considerable investigative work in the anatomic laboratory to determine the method and best site of injection in spinal anesthesia. He devised an apparatus for infiltrative anesthesia. He was the first person to differentiate between typhoid fever and malaria in Louisiana.

Dr. Matas was one of the twelve founders of the American College of Surgeons in 1913, was president of the College in 1925-1926, and was awarded an honorary Fellowship by the College in 1952. He was president of the American Surgical Association in 1909, president of the International Society of Surgery in 1936, president of the Southern Surgical and Gynecological Association (now the Southern Surgical Association) in 1910. In 1938, he was awarded the first Certificate of Merit by the American Medical Association. He was a member of practically every surgical association in the world and was an honorary member of most of them. Among his honorary memberships were those in the Royal Academy of Medicine of Barcelona, the Royal College of Surgeons of England, the National Order of Carlos Finlay, the Order of Leopold of Belgium, the Gorgas Medical Society, the Havana Academy of Medicine, and the Spanish Royal Academy. He was made a Knight of the Legion of Honor of France (Chevalier Légion d'Honneur) in 1932, and was given the rank of Officer in 1950. He received the Henry Jacob Bigelow Medal in 1926, and, in 1940, received the *Times-Picayune* L[illegible] ost eminent citizen of New Orleans for that year.

Dr. Matas was a great student and had an unprecedented fund of inforn tion. He was said by the late Dr. Will Mayo to be the world's best educat physician. One could not help but be impressed by Dr. Matas's sincerity, treme courtesy, modesty, and gentleness. If, however, courage and firmn were needed, he was amply endowed with both. In speaking of the medi student who faints when he sees his first operation, he stated: "The youth w feels and struggles at his first surgical experience shows that he is normal, th he is psychically and physiologically sound, he shows that he has feeling, th he has a human quality that will make him a humane surgeon. He is a m who will worry and who will, through his very sensibility, feel most keen the burden of his responsibility when it will be his turn to be a leader and master. It is all wrong for people to believe that the sight of blood is indiffere to the surgeon. On the contrary, the older and more experienced he is, t more anxious he is to conserve it and to see as little of it as possible in t course of his operation. Every real surgeon is happy when he can speak of h bloodless operation, and he is miserable when he has to admit that he has spill much of it in an unavoidably bloody one."

Although Dr. Matas retired shortly after the founding of The Americ Association of Thoracic Surgery, he always maintained a keen interest in t Society and its activities as well as in the tremendous developments made thoracic and cardiovascular investigations. We as an organization have great benefited because of his contributions and activities.

ALTON OCHSNER, M.D.
New Orleans, La.

Original Communications

INTRATHORACIC PHEOCHROMOCYTOMA

Including a Case of Multiple Paragangliomas of the Functional and Nonfunctional Type

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Awareness that a pheochromocytoma may occasionally occur within the thorax is of importance from two aspects. If the surgeon fails to recognize the nature of such a tumor when found in the chest, serious or even fatal complications may occur due to improper management of the patient from whom such a neoplasm is being removed. On the other hand, the investigation of a patient with paroxysmal or sustained hypertension must include roentgen studies of the chest since an intrathoracic pheochromocytoma or related type of tumor may be responsible for the blood pressure elevation. In some patients more than one pheochromocytoma may be present and one of these tumors may be located within the thorax.

Since those pheochromocytomas which occur in the usual sites in and around the adrenals cannot be visualized radiographically without special techniques, most retroperitoneal pheochromocytomas are only discovered by special roentgenograms or surgical exploration after the patient has developed intermittent or sustained hypertension and special tests have indicated that the hypertension is due to abnormally large amounts of circulating norepinephrine and epinephrine. By contrast, however, we have removed an intrathoracic pheochromocytoma from 3 patients in whom the paravertebral mass was first seen roentgenologically at a time when hypertension was not manifest. One of these patients was known to have had the tumor 3 years before hypertension was demonstrated. A second patient had the asymptomatic intrathoracic pheochromocytoma removed following the previous excision of a hypertension producing perirenal

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pheochromocytoma. The third patient had no definite hypertension but the mass was demonstrated on a routine chest roentgenogram and the biologic activity of the excised pheochromocytoma was proved by chemical analysis.

The recent literature attests to the increasing awareness of the importance of pheochromocytomas. Yet in many reports insufficient emphasis is accorded to the relatively uncommon locations in which this tumor may occur. Often discussion is limited to various diagnostic procedures which may aid in the localization of the lesion in the adrenal, perirenal, and retroperitoneal areas. More emphasis should be given to adequate roentgen examination of the thorax since a pheochromocytoma in the chest is not as rare as the literature to date would suggest. The fact that several cases have been seen in one large city and yet only a few others reported from other parts of the world lends support to this belief.

As pheochromocytomas occur in the course of the chromaffin system, the intrathoracic tumors have usually been found along the sympathetic trunk in the paravertebral region just lateral to the heads of the ribs. Such a tumor is located retropleurally. Usually the growth is a small mass which may be flattened out against the inner aspect of the chest wall in the costovertebral groove.

Roentgen demonstration of an intrathoracic pheochromocytoma may not be readily made unless the tumor is large. Since the size of a pheochromocytoma may not necessarily be closely correlated with the degree of its biologic activity, a small tumor may nevertheless be very important from the clinical standpoint. Radiographic examinations should be done with the following points in mind. On a posteroanterior film the growth may be obscured by those mediastinal structures which project laterally beyond the lateral margins of the vertebral column. Even an aortic knob or the shadows cast by the pulmonary hilum may hide the pheochromocytoma by superimposition of shadows. Obviously the cardiac silhouette may completely obscure a paravertebral tumor of even considerable size if reliance is placed entirely on a single posteroanterior roentgenogram. The lateral film may not give the help which it often does in costovertebral tumors because the pheochromocytoma is often a rather flat tumor which may not cause recognizable density in the costovertebral area. In one of our cases the lesion could not be seen on the lateral film even in retrospect. Films taken in both oblique projections may be most helpful in demonstration of a small costovertebral tumor, provided overexposure of the film is avoided.

There are several gross anatomic features of an intrathoracic pheochromocytoma which should alert the surgeon to the possibility that the tumor which he has exposed may be a paravertebral pheochromocytoma. The first thing noted may be the marked vascularity of the pleura overlying the lesion. Numerous small vessels in the tissue adjacent to the tumor may even suggest the possibility of a hemangiomatous growth. The profuse vascular supply of the small mass may be further demonstrated by the amount of bleeding which follows incision of the pleura even at a slight distance from the tumor. The intrathoracic pheochromocytoma is usually found to lie in the course of the sympathetic chain as do certain other neurogenic neoplasms. The gross appearance of the pheochromocytoma suggests a soft glandular growth rather than the usual more firm consistency of most neurogenic tumors. The pheochromocytoma is often a dark reddish brown in color.

When the surgeon encounters a mass with such gross characteristics of a pheochromocytoma, he should be particularly alert if the patient has ever had blood pressure readings of a fluctuating type or shown hypertension. But even in the absence of such evidence the possibility of pheochromocytoma may not be dismissed as one of our cases demonstrates. Changes in the circulatory status of a patient with a pheochromocytoma may occur so rapidly during manipulation and excision of the tumor that preparedness is essential. The surgeon should inform the anesthetist of the possibilities and request a very close observation of the circulatory status, with blood pressure readings every few minutes during the remainder of the operation. Norepinephrine should be made immediately available in case hypotension develops after occlusion of the blood supply of the tumor. Manipulation of the growth should be kept to a minimum so as to lessen the liberation of pressor substances into the blood stream with a possible hypertensive crisis. Phentolamine (Regitine) should be given in adequate doses if much elevation of blood pressure occurs. Pathologic examination of the excised tumor by immediate frozen section is advisable. By this means a pheochromocytoma may be distinguished from other neoplasms found in the thorax. The surgeon is then better able to guide the patient's postoperative therapy.

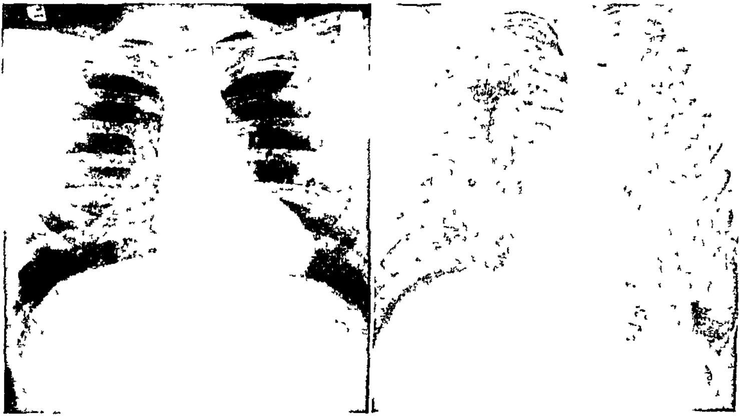
A. B

Fig. 1.—Case 1. *A*, Posteroanterior roentgenogram of chest shows a small rounded mass projecting from the mediastinal shadows just below the arch of the aorta.

B, Oblique view shows mass in left costovertebral region extending from the fifth to the seventh ribs.

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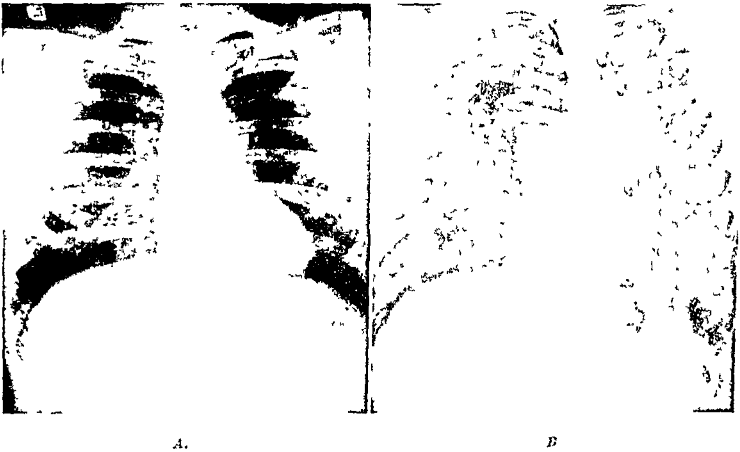

Fig 1—Case 1. *A*, Posteroanterior roentgenogram of chest shows a small rounded mass projecting from the mediastinal shadows just below the arch of the aorta

B, Oblique view shows mass in left costovertebral region extending from the fifth to the seventh ribs.

CASE REPORTS

Case 1.—(Previously reported by H. C. M.[8]) This man had a costovertebral tumor demonstrated on a chest roentgenogram when he was 22 *years old and asymptomatic.* Three years later he complained of fatigue, nervousness, palpitation, occasional dizziness, headaches, and sweating. The blood pressure was then between 210/120 and 190/100 mm. Hg. The roentgenograms showed no change in the size of the tumor (Fig. 1). At operation the possibilitiy of a pheochromocytoma was considered and frequent blood pressure readings taken. The blood pressure dropped precipitously just after the tumor was removed but responded somewhat to Adrenalin. Hypotension persisted during the first postoperative day. The blood pressure then rose again to a range between 180/110 to 160/100 mm. Hg. Not until 2½ years later was the blood pressure normal. The patient was well and normotensive 10 years later. Pathologic examination of the tumor revealed a pheochromocytoma (Fig. 2).

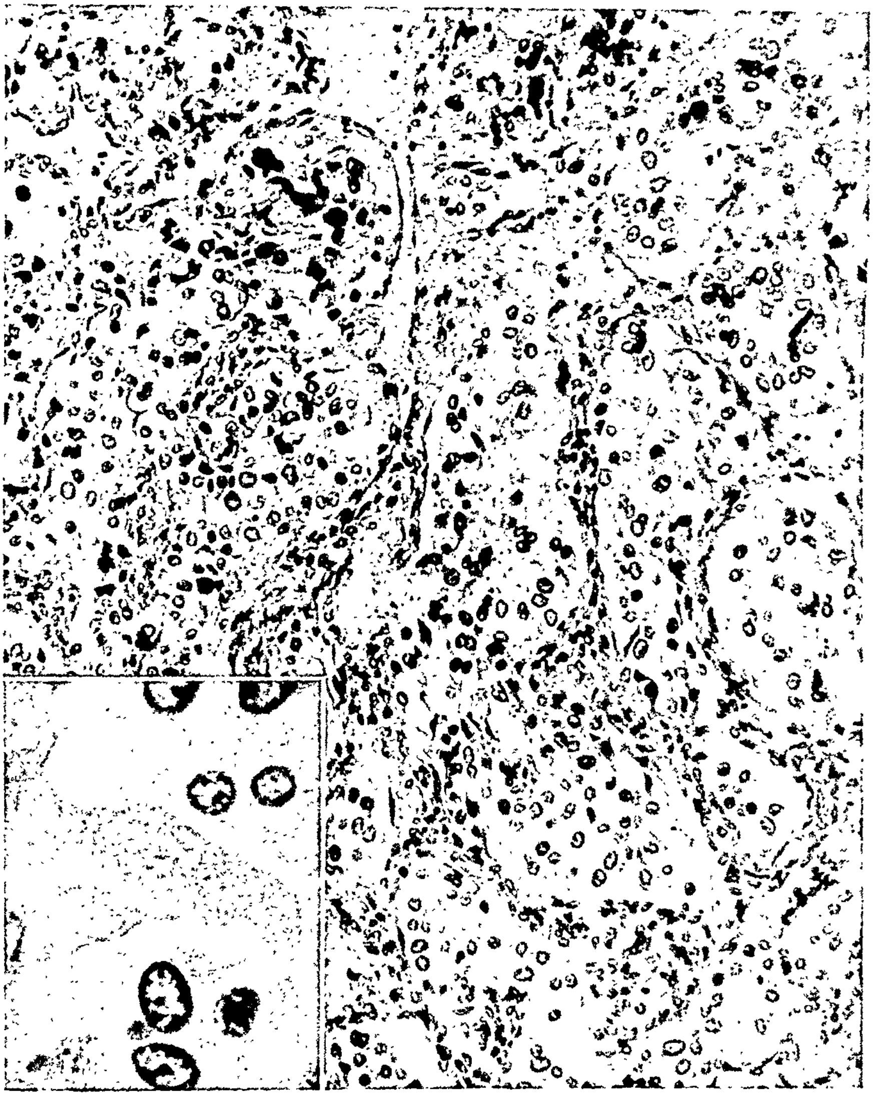

Fig. 2.—Case 1. Photomicrograph of pheochromocytoma. The characteristic arrangement of tumor cells in globules separated by capillaries is shown. Insert shows chromaphilia granules.

Comment: This case suggests that the patient with a pheochromocytoma may change from an asymptomatic status to a symptomatic hypertensive state without obvious enlargement of the tumor. Excision of a pheochromocytoma may sometimes be followed by a gradual return of the blood pressure to a normal level although usually a rather rapid decrease occurs.

Case 2.—J. C. (L.H.H.184471), a 48-year-old man, had no complaints when he was examined in a cancer detection clinic in November, 1954. Physical examination was essentially negative. Blood pressure was 120/76 mm. Hg. Roentgenogram of chest showed a rounded mass with smooth, well-defined, outer border located at the level of the right hilum, measuring about 5 cm. in diameter (Fig. 3). The lesion could not be definitely located on the lateral view. It was at first incorrectly assumed that the density was situated near the ascending aorta. On fluoroscopy, the posterior location of the mass was detected later.

When seen by one of us (H. C. M.) in January, 1955, a history was obtained of an occasional pain radiating down from the right lower thoracic region to the abdomen. A neurogenic tumor was suspected and operation recommended.

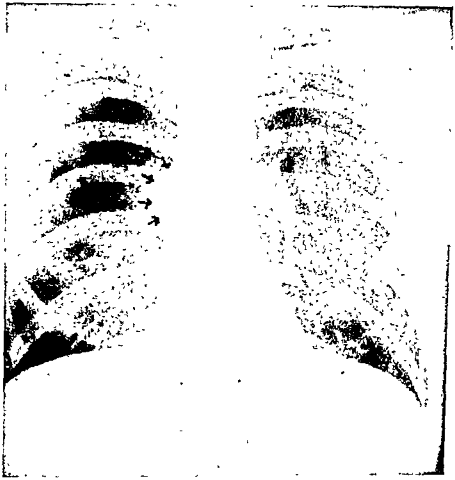

Fig. 3.—Case 2. Posteroanterior roentgenogram shows a small rounded mass (indicated by arrows) projecting out slightly from the mediastinum at the level of the right hilum.

At thoracotomy a soft, slightly lobulated tumor was found in the right costovertebral area at the level of the seventh and eighth thoracic vertebrae. The tumor was retropleural and flattened out against the chest wall; the sympathetic trunk traversed the mass. A number of blood vessels entered various portions of the tumor. The possibility of a pheochromocytoma was considered when the tumor was exposed because of the similarity to the appearance of the tumor in Case 1. Frequent blood pressure readings were taken as the growth was excised but no significant deviations occurred. Considerable bleeding was associated with removal of this 4 by 5 by 1.5 cm. pheochromocytoma.

The postoperative course was uneventful and there were no significant blood pressure changes.

Pathologic examination revealed a pheochromocytoma. No mitoses were seen. Occasionally tumor cells were seen in the lumen of blood vessels. Schmorl stains gave a positive chromaffin reaction.

The tumor specimen was analyzed by Dr. Marcel Golden[illegible] foun[illegible]ntain 2.8 mg. of norepinephrine per gram of tumor tissue, and nonmea[illegible]e.

The patient was well 39 months after operation.

Comment: This case might have been considered as a nonfunctioning paraganglioma if chemical analysis of the tumor had not been made. The gross appearance at operation was the first time that the diagnosis of pheochromocytoma was considered; this suspicion was confirmed by immediate pathologic examination. This case illustrates the fact that a functioning pheochromocytoma can be present in the absence of hypertension. It is not justified to conclude that the absence of hypertension rules out pressor activity.

CASE 3.—P. D. (P.H.844975.) This patient at the age of 8 years had first noted some difficulties in vision, but ophthalmological examination was normal. During the next several years there were episodes of emotional instability and variable visual disturbances. On Oct. 4, 1946, at the age of 11, he was admitted to the Columbia-Presbyterian Medical Center (Babies Hospital) following ophthalmological examination which revealed retinal exudate, and a blood pressure of 260/190 mm. Hg. The eye findings in this case have been reported by Bruce.[2]

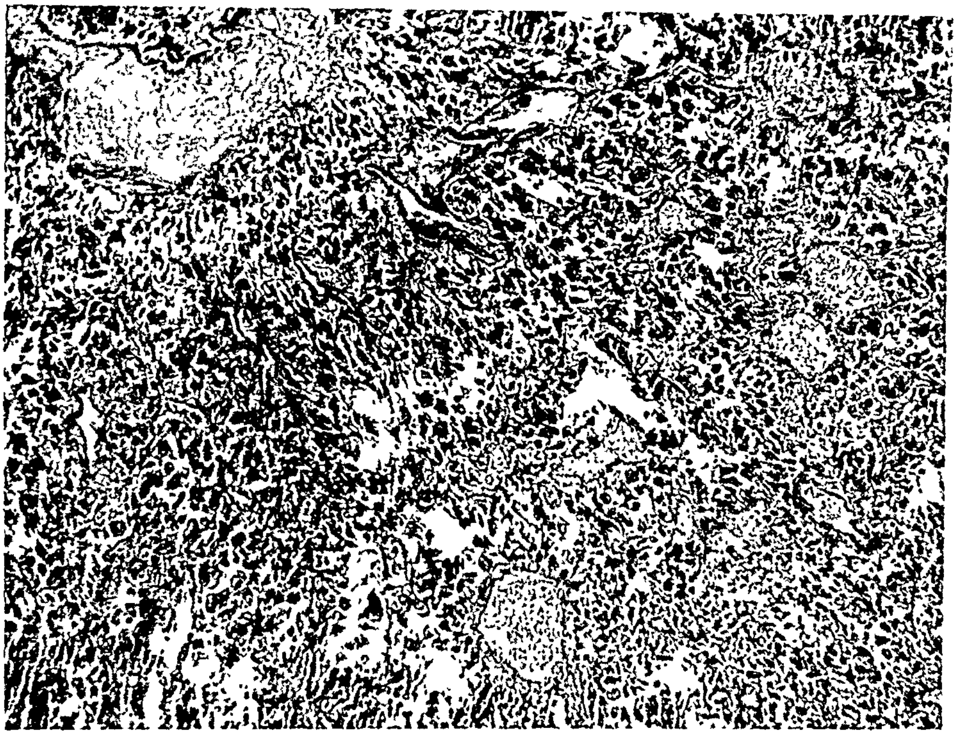

Fig. 4.—Case 3. (G.U. 7109—X-133.) Photomicrograph of the partly degenerated retroperitoneal tumor removed from the renal area in October, 1946. The organoid paragangliomatous pattern is easy to recognize.

During work-up he had episodes of severe pounding headache, pallor, sweating, abdominal pain, and nausea, during which blood pressure rose to 270/210 mm. Hg, with a pulse rate of 150. Benzodioxane tests showed a drop of blood pressure to 138/110 lasting only a few minutes, but subsequent to this there was a slow and progressive fall in blood pressure. Pyelograms showed evidence of hypoplastic right kidney.

First operation: Oct. 29, 1946 (Dr. George Cahill). Operation revealed a globular tumor, 4.5 by 4 by 2 cm. in dimensions, attached to the right renal vessels and closely applied to the inferior vena cava. The right kidney was hypoplastic, the right adrenal normal. The kidney and tumor were removed together. During operation, blood pressure rose to 160/110 mm. Hg during manipulation of the tumor, fell to 85/50 just after the tumor had been removed, and stabilized at 110/80 at the close of the procedure. Pathologic study revealed a pheochromocytoma with extensive central necrosis (Fig. 4).

Following operation, his pressure remained normal at approximately 120/80, his eye signs regressed, and he recovered without complication, being discharged on Nov. 12, 1946, 14 days after operation.

Two years later, in Sept., 1948, at the age of 13 a routine x-ray of the chest revealed a rounded shadow of homogeneous density and smooth border projecting from the mediastinum in the right posterior chest at the level of the sixth rib (Fig. 5). He was admitted to the Columbia-Presbyterian Medical Center (Presbyterian Hospital) on Dec. 6, 1948. At this

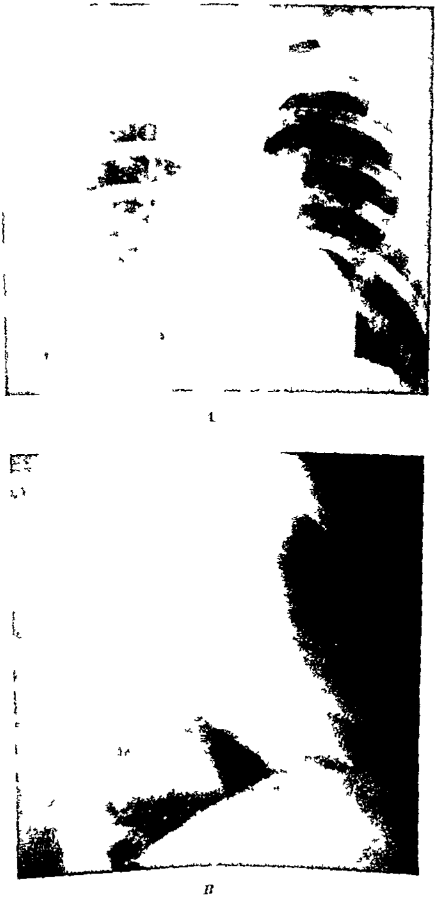

Fig. 5.—Case 3. A, Posteroanterior roentgenogram showing paraspinal thoracic pheochromocytoma at T_5 and T_6. B, Lateral roentgenogram showing paraspinal pheochromocytoma.

time he appeared to be entirely well and asymptomatic. The nephrectomy wound was well healed, his blood pressure was 110/70 mm. Hg, blood count and urinalysis were not remarkable.

Second operation: Dec. 8, 1948 (Dr. George Humphreys). A soft, extremely vascular tumor about 5 cm. in diameter was found protruding from the posterior chest wall between the fifth and sixth ribs. It apparently rose from the fifth dorsal ganglion since the sympathetic chain entered it at its upper pole and left at its lower pole. It was closely applied to the azygos vein and numerous large thin-walled veins ran from the azygos and the adjacent intercostal vessels over the tumor. All vessels surrounding the tumor were first ligated, after which the tumor was separated from the fifth and sixth ribs to which it was closely applied. There was no evidence of extension through the intervertebral foramen. During manipulation of the tumor, blood pressure rose from a preoperative level of 90/60 to 160/80 mm. Hg, falling again at the close of the procedure to 90/50. Pathologic examination revealed a 27-gram pheochromocytoma of typical histology (Fig. 6).

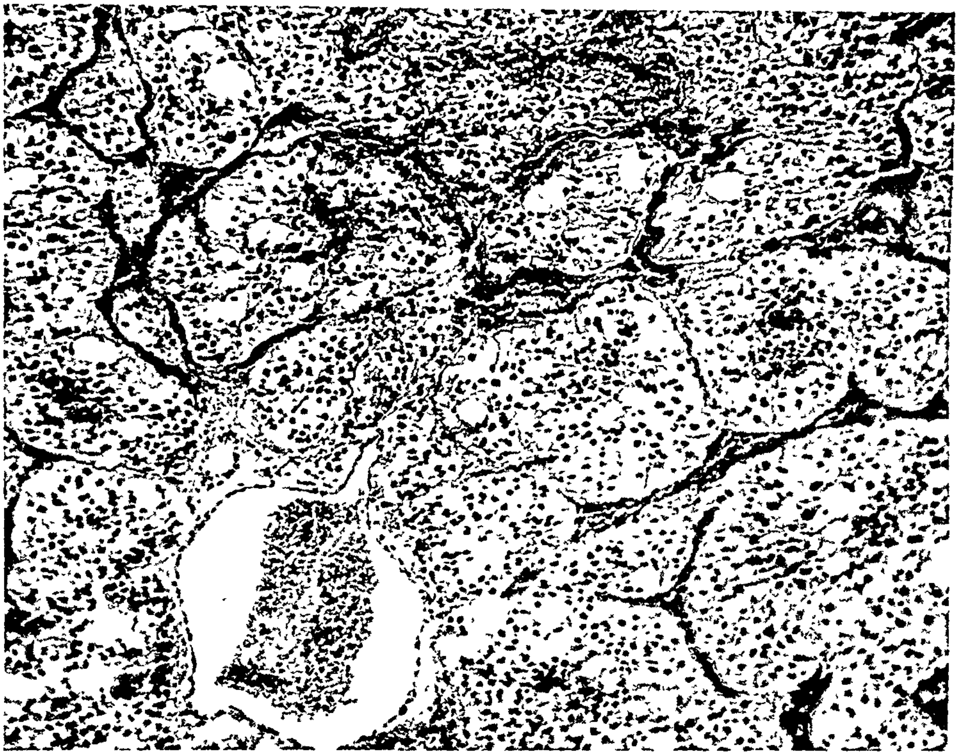

Fig. 6.—Case 3. (A-10001—X-133.) Photomicrograph of the paragangliomatous tumor removed December, 1948, from the paravertebral area at the level of the fifth dorsal sympathetic ganglion.

He made an uneventful recovery and was discharged on Dec. 17, 1948, 9 days after operation. For 5 years he remained well. In January, 1954, he developed a mass in the right lateral neck.

Third operation: Feb. 7, 1954, at Hackensack Hospital. A well-encapsulated tumor was removed which proved on section to be a nonchromaffin paraganglioma of carotid body type (Fig. 7).

Three years later, on July 24, 1957, he was again admitted to the Columbia-Presbyterian Medical Center (Neurological Institute) complaining of progressive numbness of the legs, loss of control in walking for 2 months, and back pain for 3 days. X-rays showed evidence of a destructive lesion of the fifth thoracic vertebra and physical examination showed evidence of cord compression at this level (Fig. 8).

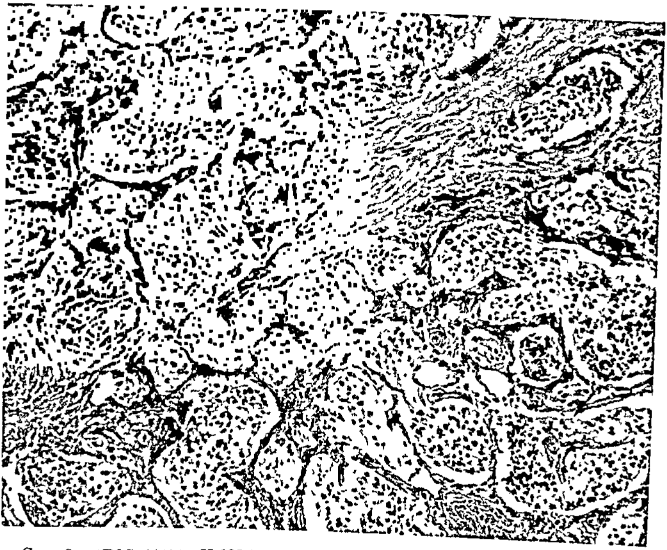

Fig 7—Case 3 (P&S 44313—X-133) Photomicrograph of the paraganglioma removed from the bifurcation of the right carotid artery in March 1954

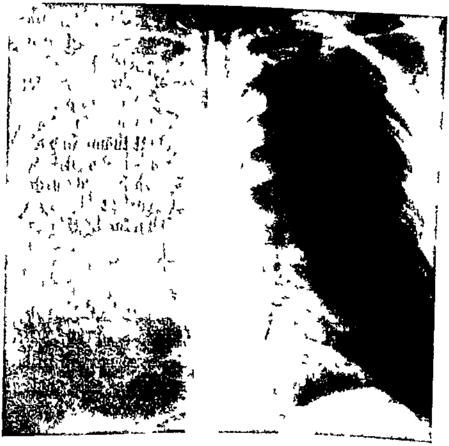

Fig 8—Case 3 Myelogram, August 1957, showing upper limit of intraspinal tumor and regeneration of fifth rib removed 9 years previously Bony destruction of the pedicle of the fifth dorsal vertebra is present but not well seen in this view.

Fourth operation: Aug. 5, 1957 (Dr. James W. Correll). There was severe spinal cord compression throughout the area of the laminectomy which extended from the second to the seventh thoracic vertebra. The tumor was found to overlay the spinal cord dorsally, to extend to the right and around the spinal cord ventrally. The tumor was entirely in the epidural space. The dura was not opened. At the termination of the procedure, the spinal cord was well decompressed with the tumor extruding through the area of the laminectomy and allowing the spinal cord to return toward its normal position. The tumor was extremely vascular. Excision of a small segment resulted in a copious loss of blood. Since the tumor extended ventral to the spinal cord and since it involved the vertebrae and mediastinum, no attempt at wide excision was made. Hemostasis was achieved with electrocautery and Gelfoam. Blood pressure remain[illegible] throughout the procedure at 140/80 mm. Hg, except for a short period when (pre[illegible] to blood loss) it fell to 110/80, returning with transfusion to the original level [illegible] of the procedu[illegible] histologic diagnosis was paraganglioma of the extradural [illegible]

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well as some dyspnea, polyuria, and nocturia. At 33 years of age he experienced a left hemiplegia. The heart was enlarged and the blood pressure varied between 170 mm. Hg and 220 mm. Hg systolic while the diastolic pressure level was about 120 mm. Hg. Roentgenographic examination of the chest showed a mass at the left apex posteriorly, which did not move on swallowing and did not compress the trachea. The patient also had a Horner's syndrome on the left side. Six years later the patient had an acute coronary occlusion and died in congestive heart failure. At autopsy, a firm mass about the size of a plum was found at the apex of the left pleural cavity. The mass was not attached to the lung and was easily shelled out. In addition to the tumor, the autopsy revealed myocardial infarction and marked arteriosclerosis of the coronary arteries, aorta, and renal vessels.

Overholt, Ramsay and Meissner[14] reported a case of an intrathoracic pheochromocytoma in a 16 year old boy who had no known hypertension prior to operation. Chest roentgenograms had demonstrated a paravertebral tumor on the left side of the chest in the region of the fourth to the seventh vertebral bodies. Other than mild heat intolerance the patient was asymptomatic and his preoperative blood pressure was 110/75 mm. Hg. During the early portion of the operation which was undertaken with a preoperative diagnosis of neurofibroma, the blood pressure rose to 240/160 mm. Hg and the presence of a pheochromocytoma was suspected. The systolic blood pressure remained at 180 mm. Hg until the blood supply to the vascular tumor was interrupted, then there was a drop in blood pressure to 90/70 mm. Hg but additional blood and Neosynephrine elevated the pressure to a systolic level of 170 mm. Hg. Due to the vascularity of the tumor, a total of 1,500 c.c. of blood was given during the operation. Nevertheless, in the early postoperative period the blood pressure again declined to a systolic level of 40 mm. Hg and, although there was again a response to Neosynephrine, the pressure was in the range of 70 mm. Hg systolic during most of the first 24 hours. The patient then made an uneventful recovery and had a normal blood pressure upon discharge from the hospital. Pathologic examination revealed the typical findings of a pheochromocytoma but no biologic assay of the tumor was performed.

Nissen[13] reported on a case of hypertension in a 22 year old woman. A thoracolumbar sympathectomy was undertaken and, during the operation on the first side, a pheochromocytoma was found along the thoracic sympathetic chain and removed. The blood pressure became normal following this operation and was still normal 2½ years later.

Cone and associates[3] recently reviewed 34 reported cases of pheochromocytomas in children. In one of their cases a chest roentgenogram had shown a paravertebral mass in the right side of the chest in the region of the seventh and eighth thoracic vertebrae which was proved at postmortem examination to be an intrathoracic pheochromocytoma. The child died following operation for massive intestinal bleeding. Autopsy also revealed a pheochromocytoma in each adrenal gland. The intestinal hemorrhage had apparently been due to an occlusive endarteritis with infarction of the intestine secondary to the marked

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Following operation, temperature rose to 103° F. for 2 days, then fell to normal, and he recovered without further complications.

X-ray therapy was begun at the Neurological Institute by Dr. Juan Taveras and completed at the Hackensack Hospital by Dr. Eric J. Ryan. At the Neurological Institute, 1,200 r in air were given over the dorsal spine from Aug. 15 to Aug. 21, 1957. At the Hackensack Hospital 1,500 r in air were given from Aug. 22 to Aug. 29, 1957.

Following operation, the patient showed evidences of progressive improvement. With the assistance of physiotherapy, he rapidly became fully ambulatory. Convalescence was complicated by homologous serum jaundice treated at the Hackensack Hospital. Fortunately, this was mild. In November, when last seen, he was carrying out all his usual activities and was preparing to return to the religious organization to which he belongs. At this time, neurological examination showed no evidence of abnormality. A satisfactory course continues.

Comment: This case is extraordinary in several respects. The patient has developed three (and possibly four) independent tumors of the paraganglionic type. The first was a functional chromaffin paraganglioma or pheochromocytoma associated with the right kidney. The second was an intrathoracic tumor of the same type originating in the fifth dorsal sympathetic ganglion. The third was a nonchromaffin paraganglioma of the right carotid body. Nine years after removal of the intrathoracic pheochromocytoma, an intraspinal tumor developed at the same level. This was also a paraganglioma, presumably chromaffin. Although extension into the foramen was looked for and not seen at the time of removal of the thoracic tumor, it is quite possible that the intraspinal tumor was a "dumbbell" extension of the thoracic tumor. It is unlikely that it arose from a dorsal root ganglion as an independent tumor. Multiple primary paragangliomas have been described[4] but the finding of both nonchromaffin and chromaffin types in the same patient is very rare.[12] Since the last tumor was not removed, it is probable that the final chapter in this case is not yet complete.

REVIEW OF LITERATURE

The first intrathoracic pheochromocytoma, an incidental finding at autopsy in a 39-year-old woman, was reported by Miller[11] in 1924. The tumor was in the right costovertebral area at the level of the sixth rib, and was about the size of two walnuts. The report did not state whether the patient had had hypertension.

The second report of an intrathoracic pheochromocytoma also diagnosed at autopsy was by Philips[15] in 1940. This man was 39 years old at the time of death, but was known to have had hypertension since the age of 29 years. He complained of episodes of cardiac palpitation and throbbing in his head, as

Von Euler and Strom[1] reported a series of cases of pheochromocytoma and included 1 case of a 31 year old man with multiple tumors in the thorax and persistent hypertension

In addition to the cases cited above, there are almost certainly others which have been reported as paragangliomas Godwin and associates[2] reported a case of paraganglioma of the upper posterior mediastinum The patient had a normal blood pressure but the gross and microscopic description of the tumor seem similar to the findings in a pheochromocytoma

DISCUSSION

Roentgen demonstration of a tumor along the course of the thoracic sympathetic chain in a patient with hypertension requires consideration of the diagnosis of pheochromocytoma Determination of the urinary catechol excretion is then in order In some cases of intrathoracic pheochromocytoma, the growth may be detected radiographically before hypertension or other clinical evidence of its chemical activity may be apparent In such cases the urinary catechol excretion may be normal Our cases demonstrate that a change in size of the tumor may not necessarily accompany the transition from a non hypertensive to a hypertensive state But a normal blood pressure does not necessarily mean that the pheochromocytoma does not contain pressor substances Chemical analysis of such tumors will further elucidate the correlation between the clinical and chemical findings

It is beyond the scope of this paper to give a lengthy discussion of the large variety of symptoms which may occur in patients with a pheochromocytoma Although, in most cases, hypertension of some type is a significant finding the absence of hypertension in some patients with a chemically active pheochromocytoma has already been indicated A patient with a pheochromocytoma which secretes sufficient norepinephrine and epinephrine to produce symptoms may manifest certain signs and symptoms not usually found in patients with essential hypertension Excessive sweating, peripheral vasomotor phenomena due to vasoconstriction, elevated body temperature, slightly elevated fasting blood sugar, somewhat elevated basal metabolic rate, tachycardia, and glycosuria may be present It can readily be seen why such patients may be confused with cases of hyperthyroidism and mild diabetes mellitus

Pheochromocytomas are frequently multiple, therefore the demonstration of a pheochromocytoma in one of the common locations does not preclude the presence of another tumor within the thorax The tumor may show familial occurrence It is sometimes associated with neurofibromatosis Malignant metastases may also be actively secreting

In recent years, additional laboratory methods of detecting the presence of a functioning pheochromocytoma have been developed These tests depend on the quantitative determination of the pressor amines in the blood or urine by fluorimetric analysis Elevated levels of epinephrine and norepinephrine in the blood are usually demonstrated if the patient has a sustained hypertension but normal concentrations of pressor amines may be found in some patients atheromatous changes produced by the severe hypertension which this cachectic 8-year-old patient had manifested. The pheochromocytoma in the thorax weighed 20 grams and contained 1.8 mg. of norepinephrine per gram of tumor tissue. This was a somewhat lower norepinephrine content than was found in each adrenal tumor. This patient's mother and younger sister also had a pheochromocytoma. In children, the incidence of bilateral and extra-adrenal pheochromocytoma is more common than in adults. Of 34 cases reported in children, a tumor was in the right adrenal in 13, and in the left adrenal in 8, in both adrenals in 9, and extra-adrenal in 7. Thus, a total of 46 tumors was found in the 34 children. The intrathoracic pheochromocytoma reported by Cone[3] is the first reported case of an intrathoracic pheochromocytoma in a child.

McLeish and Adler[10] reported a case of intrathoracic pheochromocytoma with hypertension in a 19-year-old male who noted pain in the left side of the chest following exercise. The pain was usually preceded by nausea. The patient also complained of sweats, tachycardia, faintness, and headaches. Roentgenograms showed a small tumor at the seventh rib on the left side. Cure followed successful removal of a 26-gram tumor.

Apparently the secretion of pressor amines is not limited to pheochromocytomas because Mason and co-workers[9] demonstrated noradrenaline in a thoroughly documented case of intrathoracic neuroblastoma. Their patient was a 5-month-old baby girl who had attacks of pallor, sweating, and rapid breathing lasting a few hours with apparent well-being at other times. Roentgenograms demonstrated a large rounded mass in the costovertebral area. During the attacks the blood pressure was elevated and fever was sometimes demonstrated; the attack could be abruptly ended by intravenous phentolamine. There was an increased amount of pressor amines in the urine, especially during one of the attacks. A preoperative diagnosis of intrathoracic pheochromocytoma was made and thoracotomy revealed a pink tumor arising from the left sympathetic chain. During and immediately after operation the characteristic blood pressure fluctuations, such as are encountered in the removal of an actively secreting pheochromocytoma, were observed. Microscopic examination of the tumor, however, showed a characteristic neuroblastoma and a lymph node contained a metastasis. Postoperatively the blood pressure fell to a normal range in 1 week and no further attacks of pallor, sweating, or dyspnea occurred. The child was well 1 year after operation. Assay of the 50-gram tumor showed it to contain 0.14 mg. of pressor amines per gram of tumor.

Wahl and Robinson[18] reported a case of neuroblastoma of the mediastinum with pheochromoblastomatous elements. The patient, a 4-year-old boy, died of a neuroblastoma in the upper posterior thoracic region which had metastasized diffusely. Microscopic examination of the primary tumor revealed a sympathogonioma with mixed neuroblastic and pheochromoblastic elements. Transition could be seen between primitive nerve cells and the chromaffin cells. The metastases were all of the embryonic neuroblastomatous type whereas the differentiated elements were present only in the primary growth. The child's blood pressure was not mentioned.

Von Euler and Strom[1] reported a series of cases of pheochromocytoma and included 1 case of a 31 year old man with multiple tumors in the thorax and persistent hypertension.

In addition to the cases cited above, there are almost certainly others which have been reported as paragangliomas. Godwin and associates reported a case of paraganglioma of the upper posterior mediastinum. The patient had a normal blood pressure but the gross and microscopic description of the tumor seem similar to the findings in a pheochromocytoma.

DISCUSSION

Roentgen demonstration of a tumor along the course of the thoracic sympathetic chain in a patient with hypertension requires consideration of the diagnosis of pheochromocytoma. Determination of the urinary catechol excretion is then in order. In some cases of intrathoracic pheochromocytoma, the growth may be detected radiographically before hypertension or other clinical evidence of its chemical activity may be apparent. In such cases the urinary catechol excretion may be normal. Our cases demonstrate that a change in size of the tumor may not necessarily accompany the transition from a non-hypertensive to a hypertensive state. But a normal blood pressure does not necessarily mean that the pheochromocytoma does not contain pressor substances. Chemical analysis of such tumors will further elucidate the correlation between the clinical and chemical findings.

It is beyond the scope of this paper to give a lengthy discussion of the large variety of symptoms which may occur in patients with a pheochromocytoma. Although, in most cases, hypertension of some type is a significant finding, the absence of hypertension in some patients with a chemically active pheochromocytoma has already been indicated. A patient with a pheochromocytoma which secretes sufficient norepinephrine and epinephrine to produce symptoms may manifest certain signs and symptoms not usually found in patients with essential hypertension. Excessive sweating, peripheral vasomotor phenomena due to vasoconstriction, elevated body temperature, slightly elevated fasting blood sugar, somewhat elevated basal metabolic rate, tachycardia, and glycosuria may be present. It can readily be seen why such patients may be confused with cases of hyperthyroidism and mild diabetes mellitus.

Pheochromocytomas are frequently multiple, therefore the demonstration of a pheochromocytoma in one of the common locations does not preclude the presence of another tumor within the thorax. The tumor may show familial occurrence. It is sometimes associated with neurofibromatosis. Malignant metastases may also be actively secreting.

In recent years, additional laboratory methods of detecting the presence of a functioning pheochromocytoma have been developed. These tests depend on the quantitative determination of the pressor amines in the blood or urine by fluorimetric analysis. Elevated levels of epinephrine and norepinephrine in the blood are usually demonstrated if the patient has a sustained hypertension but normal concentrations of pressor amines may be found in with paroxysmal hypertension unless the test is done at the time of a spontaneous or induced elevation of blood pressure. Elevated concentrations of pressor amines in the blood may also be found in some patients with renal insufficiency, increased intracranial pressure and lymphoma in the absence of pheochromocytoma. The elevation of the catechol level in the blood of some cases of uremia is due to impairment in the renal secretion of these substances. It might be expected, therefore, that severe renal disease associated with a pheochromocytoma might cause a reduction in the catechol output in the urine.

In some cases, the augmented secretion of catechol amines occurs intermittently but in the majority of cases it is continuous. According to von Euler and Strom,[17] there is a good agreement between the proportion of norepinephrine and epinephrine in the tumor and in the urine. While norepinephrine is increased in the urine in most all cases of secreting tumors, epinephrine is increased only in certain cases. In no instance in their series was an increased content of epinephrine alone found in the urine or tumor. Von Euler and Strom have investigated the possibility of localizing a pheochromocytoma by the catechol amine level in samples of the venous blood taken by catheter in various portions of the caval system in a case of multiple, possibly malignant, intrathoracic pheochromocytoma; samples from the inferior caval vein and the branchiocephalic veins did not contain norepinephrine but a high concentration appeared in the superior vena cava at the level where the azygos vein enters.

The body position of the patient during operation and the choice of anesthetics may be of importance for the catechol amine release from the tumor. The urinary output of catechol amine should be determined after operation in order to ascertain the completeness of the surgical treatment. A high arterial blood pressure after an apparently successful operation may be due to an essential hypertension existing before the presence of the tumor, or to vascular changes secondary to the period of elevated blood pressure caused by the tumor, or may be produced by remaining undetected tumor tissue elsewhere.

Von Euler and Strom[17] reported on the norepinephrine and epinephrine content of 15 pheochromocytomas removed from patients with hypertension. The norepinephrine content varied from 0.2 to 8.4 mg. per gram of tumor. In 7 cases, the norepinephrine was less than the 2.8 mg. per gram found by Goldenberg in our case without hypertension but, in most of these, the tumor was larger and thus the total norepinephrine content was greater. Thus, a relatively high norepinephrine concentration may be present in a small tumor without hypertension being manifest at the time. The epinephrine content of a pheochromocytoma is usually considerably less than the norepinephrine concentration. According to von Euler and Strom, the pheochromocytoma producing only norepinephrine is usually situated more or less away from the adrenal glands. Our intrathoracic pheochromocytoma which was analyzed by Goldenberg showed only nonmeasurable traces of epinephrine.

The anesthetic management of the patient with known or suspected pheochromocytoma requires special consideration.[1] In the selection of anesthetic agents, drugs which render the patient particularly vulnerable to circulatory depression would seem to be inadvisable but, on the other hand, an excitement stage would appear to be highly undesirable because it might well cause an undue outflow of pressor substances from the pheochromocytoma and thus result in an hypertensive crisis. Cyclopropane would seem to be inadvisable because of the possibility of predisposing to cardiac irritability in the presence of a high pressor level in the blood. Spinal anesthesia would not be considered for an intrathoracic pheochromocytoma and would seem undesirable anyway. The chief objectives in anesthetic management seem to be a smooth induction unassociated with any hypoxia or hypercarbia.[16]

The anesthetist must take very frequent blood pressure readings because of the rapid fluctuations which may occur. Regitine should be given if the blood pressure becomes unduly elevated during the period before the pheochromocytoma is removed. After excision of the tumor when a precipitous drop in blood pressure frequently occurs, large amounts of norepinephrine may be required to maintain the blood pressure at a satisfactory level. These patients may require amounts of norepinephrine which would be highly excessive for individuals not previously adapted to high blood pressor levels.

The literature attests to the great danger of a surgical procedure performed for some other disease upon a patient with an unsuspected pheochromocytoma. The magnitude of the operative procedure may not be of great importance because severe and fatal hypertensive and hypotensive crises have occurred with anesthesia and relatively minor surgical procedures. In any patient who manifests such unexplained circulatory derangement the possibility of an undiagnosed pheochromocytoma must be entertained. The roentgenogram of the chest must be properly scrutinized for any evidence of even a small costovertebral mass as a part of the total investigation although it is far more likely that a pheochromocytoma, if present, would be located in or near the adrenals.

Some authors have employed the term paraganglioma for pheochromocytomas which occur outside the adrenals. It seems illogical, however, to utilize a different term for a tumor of the same histologic and biologic characteristics merely because it occurs in a different anatomic location. Moreover, these tumors are derived from the chromaffin system whether they are in the adrenal area or arise in other parts of the body. One reason for the designation of the extra-adrenal pheochromocytomas as paragangliomas is the recognized fact that the presence or absence of a positive chromaffin reaction may depend in part on the fixing and staining technique employed. However, the significant factor is whether or not the tumor produces norepinephrine or epinephrine or both. It is this biologic characteristic which sets these tumors apart. But since these pressor substances may be present in the tumor without hypertension being manifested by the patient, it is obvious the chemical analysis of the neoplasm is the final criterion in doubtful cases. Thus, some tumors reported [illegible] paragangliomas in normotensive individuals may actually [illegible] ph[illegible]cytomas.

An analysis of the literature on pheochromocytoma gives multiple indications that these tumors have been frequently missed on routine postmortem examination. The difficulty in finding the tumor when it is of small size is well illustrated by 1 case in which seven surgical procedures were undertaken before the pheochromocytoma was finally located.

In 1951, Graham[6] reported on an analysis of 207 cases of pheochromocytoma with hypertension collected from the literature. In addition he encountered 41 reports of cases of tumor in which there was little or no clinical data and 32 cases of the neoplasm with no evidence of hypertension. Since that report, many additional cases have been published. It is evident that an increasing awareness of the possibility of pheochromocytoma accounts for the more frequent reports in recent years. Moreover, an increasing number are being recognized in childhood and a greater number in unusual locations are being reported. In the past few years several cases of pheochromocytoma in the urinary bladder, which resulted in hypertensive episodes associated with micturition, have been diagnosed.

The nonchromaffin paragangliomas found in the chest include tumors arising from the aortic bodies.[7] These rare lesions are not associated with hypertension. In reference to our Case 3, with carotid body tumor and pheochromocytoma, it is interesting to note that some workers have reported the extraction of a blood pressure lowering substance from a carotid body tumor. Thus, the question has arisen whether, when both types of tumors are present in the same patient, each might produce an antagonistic effect on the secretion of the other.[12]

SUMMARY

Paroxysmal or sustained hypertension in a patient with a tumor in the costovertebral region of the thorax should lead to the consideration of an intrathoracic pheochromocytoma. When operative manipulation of a soft vascular costovertebral tumor produces considerable fluctuation in blood pressure, even though no preoperative hypertension was recorded, the surgeon must consider the possibility of a pheochromocytoma and take precautions to avoid hypertensive and hypotensive crises by appropriate drug therapy during operation. Since pheochromocytomas may be multiple, an intrathoracic location must be considered as a possibility. Adequate roentgen examination of the chest combined with urinary catechol excretion determinations are the principle diagnostic aids. Surgical excision can effect a cure if instituted sufficiently early and with proper safeguards based on recognition of the nature and behavior of the tumor.

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(For Discussion, see page 673)

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(For Discussion, see page 653)

THE MANAGEMENT OF STAPHYLOCOCCIC TENSION PNEUMATOCELES BY INTRACAVITARY SUCTION TUBE DRAINAGE

Elton Watkins, Jr., M.D., and Alexander C. Hering, Commander (MC) USN (by invitation), Boston, Mass.

When infant lung tissue is infected with staphylococcic organisms, the pattern of inflammatory response predisposes to various tension phenomena within the pneumonic area. The multiple small abscess cavities represent defects in the pulmonary parenchyma subject to the disruptive elasticity of surrounding intact lung. The small bronchioles are filled with plastic exudate and cellular debris so that they function as valves, permitting air to enter the diseased tissue with each inspiration but limiting expiratory deflation. Tension areas cannot decompress by the mechanism of collateral ventilation because the surrounding lung is consolidated.

Frequently this sequence results in pleural perforations causing tension pyopneumothorax. It is also the cause of the large pneumatoceles commonly seen during convalescence. Although pneumatoceles would appear to be sequelae of the pneumonic episode (being most impressive in roentgenograms exposed during convalescence), they do appear on occasion during the acute pneumonic episode. The high incidence of early tension pyopneumothorax would suggest that the train of pathologic events which ultimately causes pneumatoceles is initiated with the primary necrotic infection and that pneumatoceles might be expected in any phase of the illness. They must either be obscured or actually prevented from expanding by pneumonic consolidation and by pneumothorax compression of the potential cystic spaces.

Although the pneumatoceles may assume alarming dimensions they have little influence upon the patient's well-being in the convalescent period—usually disappearing in time without treatment. However, the effect of a tension pneumatocele appearing in the phase of acute pneumonia may be quite different. Infants in the acute stages of staphylococcic pneumonia are desperately ill, and the slighest derangement of a precarious ventilatory reserve may be lethal.

A consideration of the mechanism of production of pneumatoceles in this illness suggests that the actual amount of lung tissue damaged is slight and that the large size of the cystic area is the result of ballooning of small necrotic foci acted upon by positive pressure gas forces. For this reason and since

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pneumatoceles are known to disappear over the course of months, leaving a normal-appearing lung, this would appear to be the situation par excellence for the utilization of conservative intubation methods in an effort to preserve a maximum degree of lung function. It must be clearly demonstrated that the course of the pneumonia is being influenced adversely by early ballooning of such a pneumatocele and, consequently, that some form of surgical treatment is necessary to preserve life

As we observed an increasing number of infants with staphylococcic pneumonia on our Dependents' Service at the Chelsea Naval Hospital after 1956, we encountered a rare situation in which two pneumatoceles caused ventilatory distress in an infant during an acute pneumonic episode. Suction drainage was used to tide this infant over the critical period. It proved to be the only treatment necessary for management of the air cysts. At that time we were not aware of any other application of intracavitary suction drainage in this disease. Recently, numerous excellent articles on staphylococcic empyema have brought up the possibility of applying suction tube drainage to staphylococcic pneumatoceles. A precise documentation of its actual application and value, however, has not appeared. It is likely that Wallman, Godfrey, and Watson bated cysts in 2 infants in the acute stages of staphylococcic pne eir description does not permit us to draw conclusions as t the procedure. Recently, Rakower and Wayl[2] report drainage caused the resolution of a pneumatocele treate sidence of pneumonia.

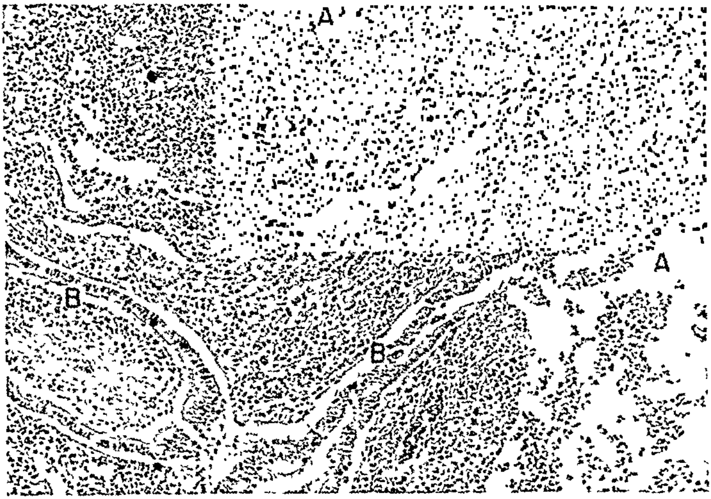

Fig. 1—Inflammatory changes in staphylococcic pneumonia predisposing to the later development of tension cysts The intense inflammatory response has resulted in the formation of two microscopic abscess cavities (*A*). The small bronchus communicating with the lower abscess is undergoing necrosis and is filled with cellular debris and exudate (*B*).

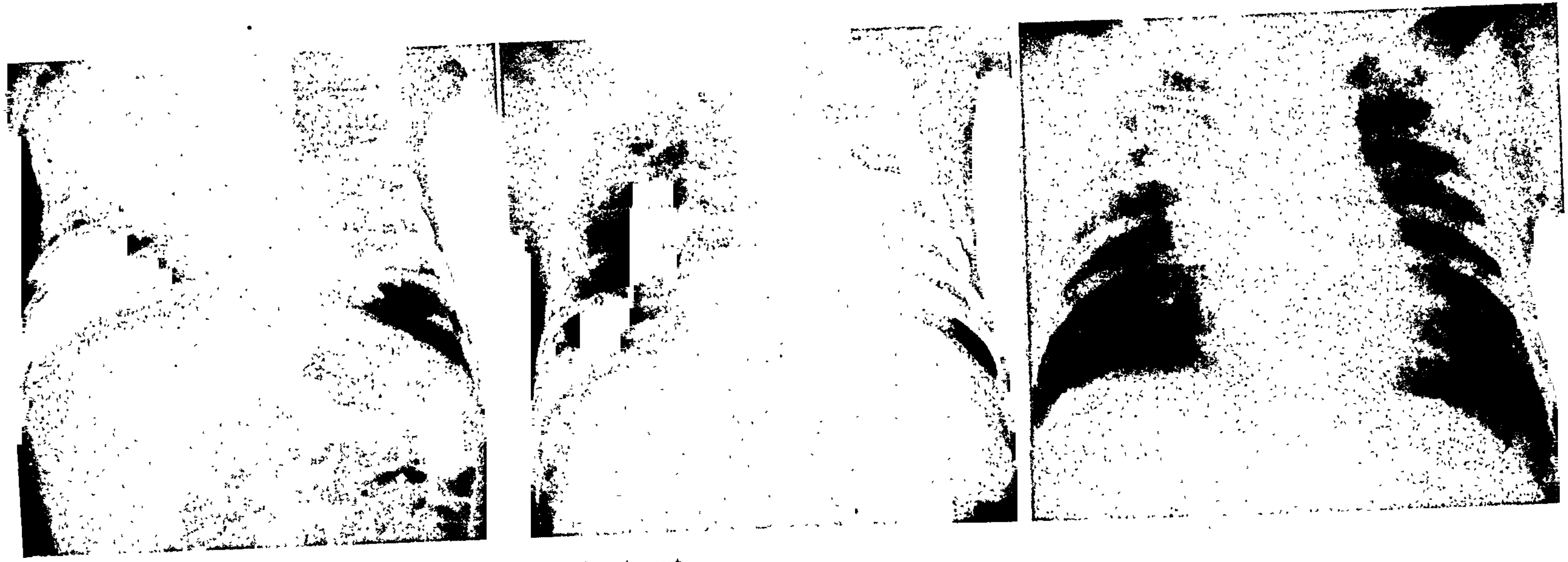

Fig. 2.—Resolution of pneumatoceles without treatment.

Left: Bilateral pneumatoceles appeared as the pneumonic process subsided.

Middle: Although the pneumatoceles in the right upper lung field distended enough to cause mediastinal displacement 25 days later, the child was experiencing only slight dyspnea on exertion and consequently was managed conservatively.

Right: Two months later, the cysts were resolving. Patient was asymptomatic. Cysts completely disappeared in subsequent roentgenograms.

CLINICAL EXPERIENCE LEADING TO THE APPLICATION OF INTRACAVITARY SUCTION

Between January, 1956, and April, 1958, we treated 12 infants with pneumonia attributable to staphylococcic infection. In each instance, the organism could be cultured from blood, empyema fluid, sputum, or throat swabbings. The last-mentioned culture source was reliable in indicating the offending pathogen since each of the 12 patients presented characteristic signs of staphylococcic disease: empyema, tension pyopneumothorax, pneumatocele, or a combination of such complications. Bacteriologic studies demonstrated the expected resistance to penicillin, streptomycin, and the tetracyclines, with sensitivity to chloramphenicol, erythromycin, and Albamycin. Analysis of hemolytic activity and coagulase activity was incomplete. Phage typing was not carried out.

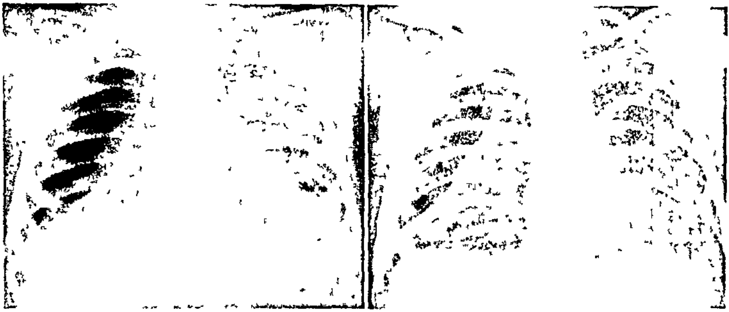

Fig. 3.—Differentiation of an atypical pleural pocket from pneumatocele.

Left. A tension pneumothorax may be misinterpreted as a pneumatocele by an inexperienced observer. A small pneumatocele in the collapsed right lung demonstrates the characteristic rounded appearance and surrounding lung tissue, features not evidenced by the elongated tension pneumothorax.

Right. A later film demonstrated expansion of the right lung posterior to the pyopneumothorax pocket. The pneumatocele is now irregular in appearance, probably as a result of resolution of bronchial inflammation and decompression of the cyst.

The 12 patients ranged in age from 1 week to 6 years. Eight were under 1 year of age. No sex predilection was apparent in the small series, 7 of the patients were males and 5 were females. Pyopneumothorax was the sole pleural complication, occurring in 7 of the 12 patients. All of the patients with empyema had an associated air leak. Two patients with small accumulations of air and exudate could be managed by needle aspiration alone. This was utilized as the sole means of treatment only when toxicity was slight, the pockets were small, and accumulations were slow in developing. The sustained maintenance of negative intrapleural pressure after aspiration was an indication for the continuing application of needle aspiration. If any suggestion of toxicity or rapid accumulation of fluid or air was observed, trocar intubation was carried out, connecting the No. 16 Fr. catheter to suction of −10 to −15 cm. of water. One patient did not come under our care until a small pocket of fluid and air was well on the way to resorption without the aid of needle aspiration. Since pneumatoceles subsequently developed, we have li[illegible] plication in this case as pyopneumothorax, although we [illegible]

TABLE I

CASE	AGE AND SEX	CULTURE SOURCE	PLEURAL COMPLICATIONS		PNEUMATOCELES				
			TYPE	TREATMENT	NUMBER	PNEUMONIA	TREATMENT	DAYS, ONSET OF PNEUMONIA TO APPEARANCE	MONTHS, ONSET OF PNEUMONIA TO DISAPPEARANCE
1	3 mo. F	Throat	Pyopneumothorax	None	2	RML	Observation	13	2½
2	19 mo. M	Empyema	Pyopneumothorax	Intubation	0	L RUL	---	--	--
3	2 mo. M	Blood	None		2	LLL	Observation	29	6½
4	9 mo. F	Throat	Pyopneumothorax	Needle *aspirations* (*multiple*)	1	RLL	Observation	24	1½+
5	2 mo. M	Empyema	Pyopneumothorax	Intubation	0	RLL	---	--	--
6	17 mo. M	Empyema	Pyopneumothorax	Needle aspirations (3)	3	RUL RLL	Observation	20	1
7	3 yr. F	Throat	None		1	RLL	Observation	11	1+
8	6 yr. M	Throat	None		2	LLL RUL	Observation	19	2+
9	2 mo. F	Throat	None		2	RLL LUL	Observation	10	2+
10	1 wk. M	Empyema	Pyopneumothorax	Intubation	0	R L	Dead		
11	2 mo. M	Throat	None		3	RUL RML RLL	Observation	17	11 days+
12	2 mo. F	Empyema	Pyopneumothorax	Intubation	4	R	Intubation	14	2

as to the character of the fluid Intrapleural tubes were removed when the lungs were expanded, pressure fluctuations were slight, and only after 24 hour periods of clamping were not associated with reappearance of air or fluid

It was interesting to note that the 9 infants in whom pneumatoceles developed showed roentgen evidences of cyst formation early, within 10 to 29 days after onset of the pneumonia In most of the 9 infants, pleural complications and toxicity from the pneumonic process were well on the way to resolution once the pneumatoceles appeared However, in 1 case, the period of toxicity was prolonged and the infant showed pleural disease and ventilatory disturbance as a result of ballooning cysts during the acute illness

This patient was treated successfully by intracavitary suction tube drainage We did not consider tube drainage necessary in any of the other patients in whom pneumatoceles developed In several of these patients, the cysts assumed alarming proportions on the roentgenogram and, in 1 infant, dyspnea was attributable to cyst distention However, the pneumatoceles resolved in every instance as we patiently adhered to the doctrine of masterful inactivity

Of the 4 patients in whom pyopneumothorax did not develop, pneumatoceles developed subsequently in each, while each of the 3 patients without pneumatoceles had a large pyopneumothorax requiring intubation We have hypothesized that pleural accumulations might have a compressive effect which inhibits the disruption of the small abscess focus

The only death in the series occurred in a 1 week old infant with multiple congenital anomalies An overwhelming infection developed in this case despite adequate pleural drainage The nature of the pneumonic process is shown in the photomicrograph of the infected lung (see Fig 1)

All of the remaining patients are now asymptomatic Five patients have shown x-ray evidence of complete resolution of the pneumatoceles within 1½ to 6½ months after onset of the pneumonia The remaining 4 patients with pneumatoceles are showing resolution during observation periods of 11 days to 2 months after the onset of the pneumonia

CASE REPORT

A female infant, aged 2½ months, was transferred to our service from another hospital on Jan 25, 1956 Although no respiratory difficulty had been demonstrated at delivery and the early neonatal period had been uneventful, nasal obstruction and cough developed on Jan 5, 1956, when the patient was 53 days old A roentgenogram of the chest showed opacification of the right lung field By Jan 13, 1956, an air fluid level had developed in the right pleural space Respiratory distress became increasingly severe Hemolytic streptococcus and *Staphylococcus aureus* could be cultured from the purulent exudate in this pocket

On Jan 14, 1956, myocardial decompensation was suggested by the findings of tachycardia, cardiac enlargement, and hepatomegaly Digitoxin was added to the current antimicrobial therapy of chloramphenicol and streptomycin, and the right pleural space was drained through the bed of the eighth rib The infant's condition remained critical following the intubation, and she was transferred to our service

On admission, the child appeared pale and showed considerable respiratory distress The heart rate was 164 and respiratory rate was 66 Breath sounds were diminished and the percussion note was flat over the entire right hemithorax No rales [illegible] ble,

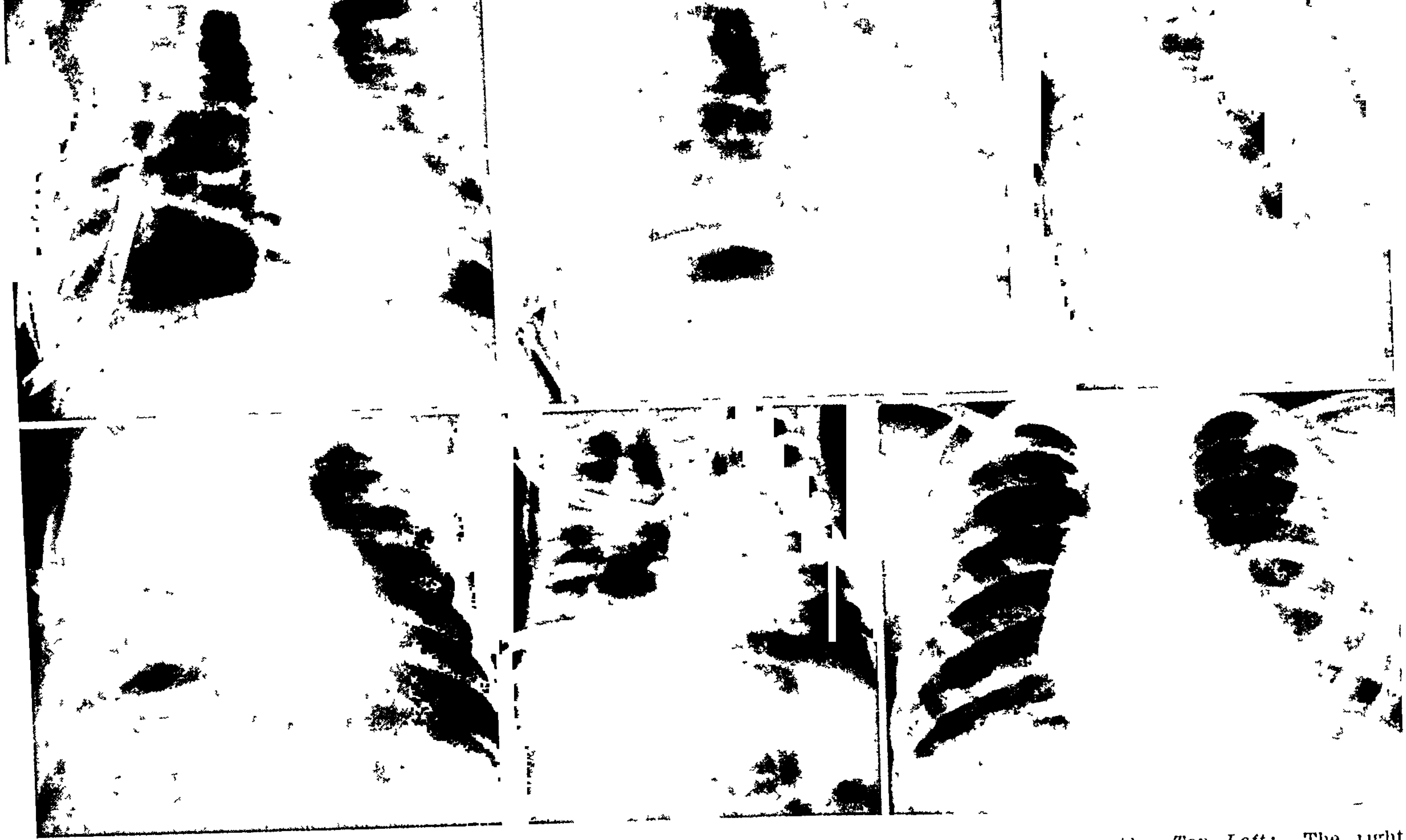

Fig 4 —Management of two pneumatoceles by intracavitary suction tube drainage (see case report) *Top Left*· The right lower lung field is replaced by a large tension cyst herniating into the posterior mediastinum Other pneumatoceles herniate superiorly into the left lung field When the intrapleural tube was clamped, air leaked into the pleural space, demonstrating the extent of the empyema pocket and the intrapulmonary nature of the cystic shadows *Top Middle* After insertion of the tube into the inferior cyst, it was kept deflated but the superior pneumatoceles have expanded *Top Right* Lateral view demonstrating deflated posterior pneumatocele and tension cyst anteriorly

Bottom Left Both pneumatoceles are deflated by intracavitary suction tubes The position of the mediastinum was improved and the left lung was better aerated *Bottom Middle* When the tubes are clamped for 10 minutes, air accumulates in the upper pneumatocele but not in the lower one *Bottom Right* Film 1 year later showing resolution of pleural and intrapulmonary processes no stridor could be heard. A No. 14 Fr. catheter was secured in an incision in the right posterior axillary line. The liver was palpable 1.5 cm. beneath the right costal margin. No cyanosis was present.

White blood cells numbered 16,200 per c. mm. with a differential count of 59 neutrophils and 41 lymphocytes. The red cells numbered 3,240,000 per c. mm. Hemoglobin concentration was 9.0 Gm. per 100 c.c. The urine contained white cells and granular casts. A culture of fluid from the thoracotomy tube yielded a heavy growth of beta hemolytic *Staphylococcus aureus,* which was moderately sensitive to chloramphenicol and bacitracin, slightly sensitive to Achromycin, and resistant to penicillin, streptomycin, Aureomycin, Terramycin, and Aerosporin. An electrocardiogram showed changes consistent with a digitalis effect.

Continuous suction at a subatmospheric pressure of −10 cm. of water was applied to the chest tube. Small amounts of air bubbled from this tube. Digitoxin and transfusions of whole blood were given. Chloramphenicol was administered intramuscularly in doses of up to 200 mg. every 24 hours. Large doses of erythromycin were also given. Heavily misted oxygen was administered.

On the second hospital day, it was necessary to change the intrapleural tube to establish an air-tight connection through the area of rib resection. The patient then passed numerous loose mucoid stools culturing Pseudomonas organisms. To combat the diarrhea intravenous fluids were given and neomycin started by gavage to a total of 200 mg. every 24 hours. Although respiratory distress diminished for several days, by January 30 the child was dyspneic and cyanotic. The respiratory rate rose to 60 and was accompanied by soft tissue retraction. She appeared to be moribund, with signs of vascular collapse. A chest roentgenogram showed that the size of several pneumatoceles had increased as the empyema had resolved. Cysts in the right upper lung field caused the lung to herniate into the superior mediastinum, and a giant inferior pneumatocele herniated into the posterior mediastinum. The entire mediastinum was deviated by the compression. A small amount of air had accumulated within the empyema pocket in the short time required to transport the patient to the Radiology Department. This proved useful, however, in demonstrating the limits of the empyema pocket, excluding pleural loculation as a source of cystlike artifact and delineating the cystic structures as lying within the substance of the right lung.

In view of the critical situation and the possibility that the inferior pneumatocele might be interfering with the circulation by compression of the inferior vena cava, this cyst was intubated. A calibrated 18 gauge needle was inserted into the pneumatocele under Xylocaine anesthesia. As we prepared to measure manometric pressures the barrel blew out of the syringe. After this incident, the pressure measured +15 to +20 within the cyst and could be reduced to −2 cm. by the withdrawal of about 10 c.c. of air. However, it was possible to continue aspirating unlimited amounts of air, thus confirming the free bronchial passage of air into the cyst. When continuous needle aspiration was interrupted pressure rose to +20 cm. of water in a matter of 1 or 2 minutes. Respiratory distress was diminished during the moments of needle decompression but increased with interruption of the continuous aspiration. The intrapleural tube showed subatmospheric fluctuations during this period.

In this situation it was obvious that intermittent needle aspiration of the pneumatocele would be ineffective, consequently a catheter was inserted into the cyst by the trocar technique. For 48 hours after intubation large volumes of air continued to bubble, although −15 cm. bottle suction could be maintained. The infant's condition improved strikingly during this period.

Progression of the size of the superior pneumatoceles caused the return of respiratory distress and cyanosis on Feb. 2, 1956. Needle pressures were strongly positive within the superior pneumatocele but remained subatmospheric in the inferior cyst. It was again possible to aspirate large volumes of air only to have it reaccumulate promptly under strong positive pressure. Consequently another tube was inserted into the superior pneumatocele. The following day, roentgenograms were exposed before and after a 10 minute period of clamping of the two pneumatocele tubes. During this time the inferior cyst remained compressed but the superior pocket ballooned to a large volume. It had been possible to clamp and remove the intrapleural tube without the recurrence of pyopneumothorax despite the fact that the inferior pneumatocele tube, at least, traversed free pleural space.

By February 7, the patient showed steady improvement. No air accumulated within the inferior pneumatocele during a 24-hour period of tube clamping, so the tube was removed. On February 15, the superior cyst tube was removed. During the next few days small amounts of purulent material accumulated within the empyema pocket and were aspirated with a syringe and needle. The tube tracts remained decompressed. Several smaller pneumatoceles in the right lung showed no tendency to expand. Antimicrobial therapy was discontinued on February 24 and the child was discharged from the hospital on February 29 of that leap year. She has remained well to the present date. Roentgenologic resolution of the remaining pneumatoceles occurred within 1 month after discharge, at which time pleural reaction was negligible.

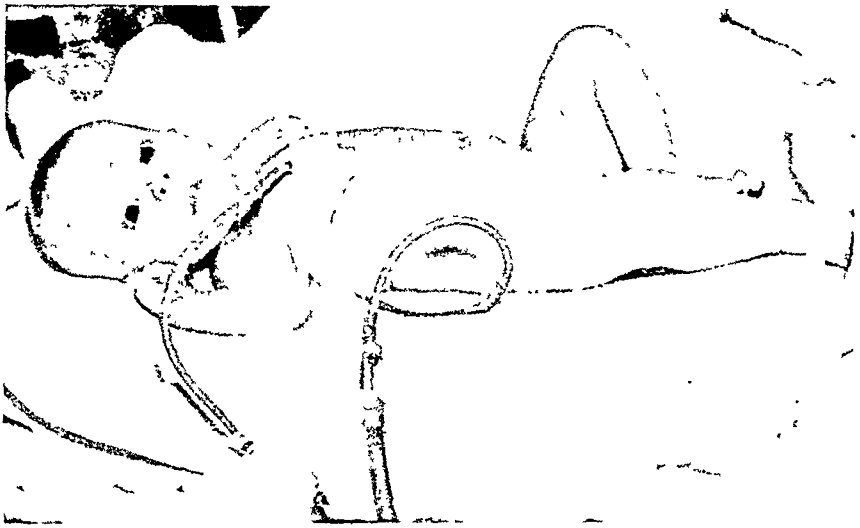

Fig. 5.—Appearance of the child with two intracavitary suction tubes in position.

Comments on Intubation Technique.—Since we have been impressed with the lack of control of the depth of penetration when intercostal tubes are placed by the trocar method, we have used a series of measurements to ensure accurate placement of the tubes both in empyema pockets and in pneumatoceles (which are small in volume compared to the usual tension pneumothorax). The details of placement and measurement are shown in Figs. 6 and 7. Centimeter calibration rings are useful on the Ochsner trocar and 18-gauge aspiration needle, although the same results may be obtained by temporarily marking the necessary measurements on an ordinary trocar.

Rib resection has not been necessary to allow passage of the large trocar through an interspace. Even when the trocar is larger than the space, the mobile rib cage of an infant tends to spread if the blade of the trocar is accurately pointed between the ribs into the intercostal muscle. A flat surface of the triangular trocar blade should be parallel to the edge of the upper rib so as to minimize the hazard of injuring intercostal vessels. The danger may also be lessened by directing the trocar slightly caudalward as the blade penetrates the intercostal bundle. In this manner the trocar point is directed closer to the upper margin of the inferior rib and away from the intercostal vessels We have not encountered bleeding after tube placement—a fortunate result of our precautions or of the tamponade effect of the large tubes we have used

The point of tube passage was selected by careful analysis of posteroanterior and lateral chest roentgenograms We have felt that fluoroscopy is not necessary and have been reluctant to subject seriously ill infants to the handling which is necessary for such an examination

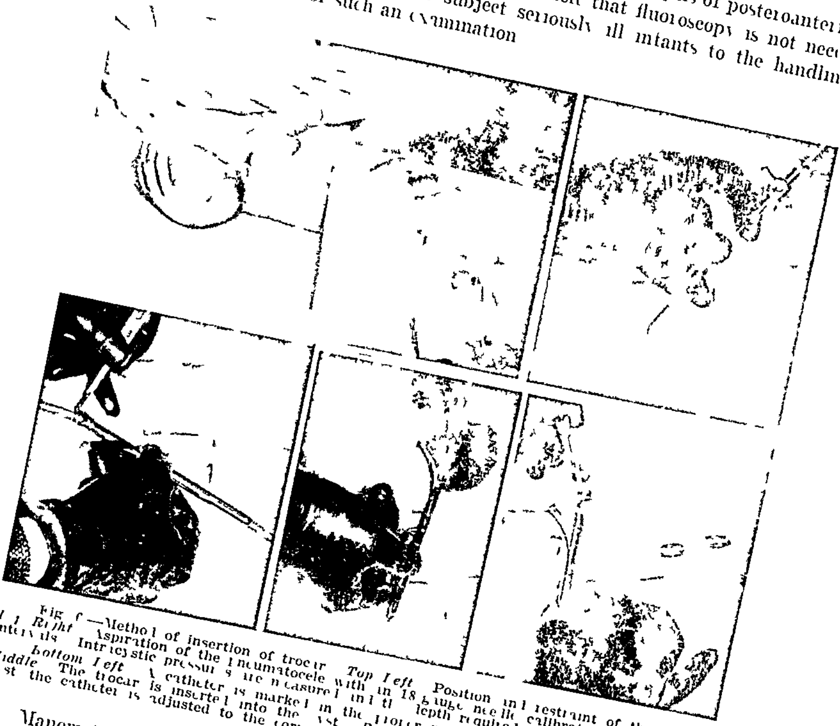

Fig 6 —Method of insertion of trocar *Top Left* Position and restraint of the infant *Top Right* Aspiration of the pneumatocele with an 18 gauge needle calibrated at centimeter intervals Intracystic pressures are measured and the depth required for penetration noted *Bottom Left* A catheter is marked in the proper position within the trocar *Bottom Middle* The trocar is inserted into the cyst *Bottom Right* With the trocar within the cyst the catheter is adjusted to the correct depth

Manometric pressure measurements have proved useful in demonstrating the dynamics of gas exchange into the cysts and empyemas An ordinary pneumothorax machine has been used The rapid loss of subatmospheric pressure in the minutes after aspiration promptly indicates the necessity for continuous tube drainage Pressure disparities in various pockets on aspiration indicate the absence of free communication between the various pockets

The large bore of a No 16 Fr catheter is useful in

amounts of air and minimizing obstruction caused by exudate. Both empyema and pneumatocele catheters have been irrigated with small amounts of saline solution to ensure patency. Because of the bronchial communication, we have placed the patient in such a position that the tube is dependent in the thoracic cavity during the period of irrigation. No signs or sequelae have been suggestive of bronchial contamination with use of the irrigating solution.

Since we demonstrated rapid ballooning of one pneumatocele with a 10-minute period of tube clamping, we now transport all patients to the Radiology Department in their beds, with continuous suction drainage being maintained to preclude transient gas accumulations. We do not remove the catheters until it is evident that air-fluid accumulation will not reappear during a 24-hour period of tube clamping.

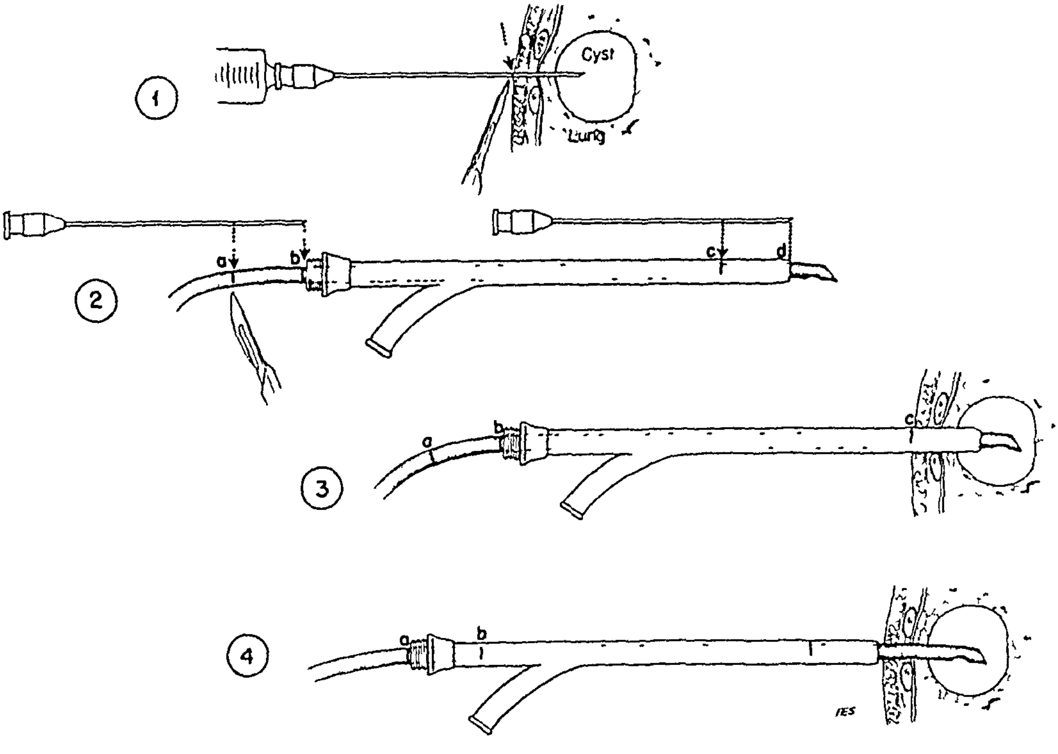

Fig. 7.—Method of adjusting the depth of penetration of the catheter.

(1) The cyst is aspirated and the depth of penetration of the needle noted

(2) This depth of penetration is then measured off (*a—b*) on the catheter, lying in the correct position in the trocar and on the trocar tip (*c—d*).

(3) The trocar is inserted to the depth "*c—d*," placing its tip within the cavity The catheter is inserted into the trocar to a depth of point "*b*." It is now in correct position within the cyst.

(4) The trocar is drawn back to the skin level and the position of the catheter is adjusted finally by bringing point "*a*" flush with the cannula orifice

SUMMARY

1. Twelve infants and children with staphylococcic pneumonia were treated at the United States Naval Hospital, Chelsea, Mass., between January, 1956, and April, 1958. Pyopneumothorax developed in 7 of these children. Nine

showed pneumatoceles at some time during the course of the illness. One premature infant died with multiple congenital deformities and pyopneumothorax. The remaining patients are asymptomatic and show roentgenologic changes of resolution.

2. Pyopneumothorax was treated by repeated needle aspirations when slight and by intercostal tube drainage when extensive.

3. All 9 patients with pneumatoceles show either complete resolution within 1½ to 6½ months after onset of the pneumonia, or progressive resolution when observed for periods of less than 2 months.

4. Eight of the patients with pneumatoceles required no specific treatment. In 1 infant, intracavitary suction tube drainage was lifesaving in that it prevented tension distortion of the thoracic contents by two pneumatoceles which appeared early in the toxic phase of the pneumonia. The tubes were introduced without staging the procedure and, in at least one instance, traversed free pleural space without aggravation of the pre-existing empyema. The alternative of cyst excision is regarded as undesirable because of the probability that salvable lung tissue would be excised, and because thoracotomy would be a formidable procedure in the presence of empyema and pneumonic toxicity.

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1. Wallman, I. S., Godfrey, R. C., and Watson, J. R.: Staphylococcal Pneumonia in Infancy, Brit. M. J. 2: 1423, 1955.
2. Rakower, J., and Wayl, P.: Monaldi Drainage in the Management of Postinfectious Pulmonary Cysts, J. Pediat. 52: 573, 1958.

DISCUSSION

(PAPERS BY MAIER [PAGE 625] AND WATKINS [PAGE 642] AND THEIR ASSOCIATES)

DR. DAVID C. SABISTON, Baltimore, Md.—The rising incidence of all types of staphylococcal infections during the past several years has indeed been impressive. One of the more important problems which we have encountered has been the marked increase of staphylococcic pneumonia occurring in infants and young children. Although once an uncommon disease, it is now of frequent occurrence. I would like to comment briefly on several points regarding management and prognosis in a group of patients studied at the Johns Hopkins Hospital. During the 2 year period, 1951-1952, there was a total of 6 cases of staphylococcic pneumonia seen in the Department of Pediatrics. The striking rise in the incidence of this disease is shown by the statistics of the past 3 years (1955-1958) during which time there have been 61 cases. In this group, 23 or 38 per cent have been managed by closed intercostal catheter drainage in addition to antibiotic therapy.

STAPHYLOCOCCAL PNEUMONIA IN INFANCY AND CHILDHOOD—61 CASES

Closed intercostal drainage (catheter)	23 (38%)
Open drainage	1
Pulmonary decortication	1

Results in Staphylococcal Pneumonia, 1955-1958

	Cases	*Deaths*	*%*
Primary	55	4	7
Secondary*	6	6	10
Total	61	10	

*Primary disease: cystic fibrosis, nephrosis, hypogammaglobinemia.

(slide) The indications for drainage have been primarily the presence of large tension pneumatoceles, a tension pneumothorax, or extensive empyema. Of the 61 patients studied, 55 were primary and in this group there were 4 deaths (7 per cent).

(slide) It is interesting that 3 of the 4 patients who died were less than 3 months of age and, in each instance, the course was characterized by a rapidly progressive toxemia leading to death within 48 hours. Each of the 6 patients who had staphylococcic pneumonia secondary to a systemic disease died as a result of the combination of their illnesses.

We agree fully with the authors that catheter drainage should be employed frequently in the management of the intrathoracic tension complications which are often associated with staphylococcic pneumonia in children. It has been our experience that it is often necessary to place multiple catheters within the chest and that, in some instances, these must be replaced on several different occasions. All the patients we have observed have been treated with a combination of large doses of bactericidal and bacteriostatic drugs. Penicillin, in combination with either Chloromycetin or Albamycin, has been the antibiotic of choice in the majority of cases. With the combination of chemotherapy and closed surgical drainage, good results have been obtained in the patients with primary disease. Open drainage has been necessary in only one instance.

In the last slide, the initial chest film of this patient demonstrates multiple small pneumatoceles and empyema in the right lung. A tension pneumothorax developed and this failed to respond to an intercostal catheter. Later it was necessary to treat the child with rib resection and open drainage. Marked clinical improvement followed but the second film shows a large empyema cavity demonstrated by the injection of contrast media. Pulmonary decortication was then performed by the Resident, Dr. Merril Brown, with complete reexpansion of the lung. The final film shows the late postoperative result and the child is now well.

In closing, I should like to compliment Dr. Watkins and Dr. Hering on their very interesting presentation.

DR. JEROME R. HEAD, Chicago, Ill.—In reading the abstract of this paper in the program, I was very much interested to learn how a catheter could be put into an intrapulmonary cavity with trocar and cannula without the production of pneumothorax. Now, having heard the paper, I can understand that this was attempted and that it was successful because the patient had had an empyema which ensured the presence of adhesions between the lung and the chest wall. My experience with intracavitary suction has been limited to tuberculosis and large emphysematous blebs and in these cases it is essential to do a two-stage operation or, at least, to be sure that the two layers of pleura are adherent before making an opening into the lung. I think that it would be too bad if anyone left this meeting with the feeling that under ordinary circumstances it is safe to insert a trocar into the lung without first exploring the pleura.

DR. MAX G. CARTER, New Haven, Conn.—May I congratulate Dr. Watkins for an excellent presentation of an increasingly important subject. I would like to re-emphasize what has been stated about the necessity to distinguish between the presence of a true pleural empyema and intrapulmonary air cysts arising as a result of staphylococcal infection. We see 10 or more of these patients each winter and have observed the development of cystic areas in the involved lung which may persist long after the temperature has become normal and the patient looks clinically well. Ultimately, within 3 to 6 months these all clear.

On the other hand, an actual empyema demands prompt attention by intercostal catheter as discussed by Dr. Watkins. It has been our practice to use a small polyethylene catheter placed through an intercostal needle early in the disease when the fluid is thin, thereby achieving total expansion with little trauma. If thick purulent material is present, of course a larger catheter is needed.

DR. OSLER ABBOTT, Emory University, Ga.—This discussion was not returned.—EDITOR.

WATKINS (Cl[illegible] I [illegible]ant to thank all the discussers for their comments. We have hoped to promote [illegible] perusal of the current status of staphylococcic pneumonia. In relation to Dr Potts's [illegible]t we have been impressed with the fact that patients develop[illegible] pneumatoceles [illegible] very large pyopneumothoraces, whereas there seems to be a [illegible] incidence [illegible]cele formation in patients who do not develop pyopneumothorax. We have po[illegible] compressive effect of the pyopneumothorax may inhibit [illegible]ruption of the small abscesses which give rise to the pneumatoceles. This reported case differed [illegible] usual patient only in that pneumatoceles developed during [illegible] period when the pl[illegible]s[illegible]tive and the patient was toxic. Otherwise, pleural and cyst complicatio[illegible]d typical.

I [illegible]ould comment on Dr [illegible] remarks by stating that I would not hesitate to intubate across a free pleural space if [illegible]tuation warranted because of the serious nature of the disease and the urgent necessit[illegible]nitive correction. I would attempt to obtain artificial pleural symphysis using the [illegible] described by Dr Abbott, but even if this failed, it would actually seem best to [illegible] the[illegible] a free pleural space (under antibiotic therapy) and watch carefully [illegible]ral leak requiring pleural intubation. The only alternatives to this course of [illegible] thoracotomy certainly lethal, waste valuable time staging a Monaldi type of [illegible] allow an intolerable tension situation to continue. Fortunately I suspect th[illegible] will [illegible] see trouble from tension pneumatoceles when the patient is all from pleural [illegible] at

We have made every effort [illegible] tubes because of the large volume of the air leaks and because of the natur[illegible] aspirated from a pneumatocele. The exudate which is usually small in volume [illegible] thick and tends to occlude small tubes. Consequently, we have used No 16 Fr [illegible] to introduce into the cysts. I would not use a plastic tube passed through a n[illegible]se it has an exceedingly small lumen and I would think that it would become blocked [illegible]tly

TOPOGRAPHY OF THE HUMAN CORONARY ARTERIES IN RELATION TO CARDIAC SURGERY

Thomas N. James, M.D. (by invitation), and George E. Burch, M.D. (by invitation), New Orleans, La.

DISTURBANCES in cardiac rhythm and conduction of impulses are recognized as important problems in cardiac surgery. Although every attempt is made to spare the conduction pathways and the sino-auricular (SA) and atrioventricular (AV) nodes, little attention has been directed to the blood vessels supplying these areas. This has been largely due to meager knowledge regarding their circulation.

In a study of 70 human hearts by injection of Vinylite into the coronary arteries, followed by hydrochloric acid corrosion, observations have been made on the blood supply to the conduction system. The study provided a spatially oriented preparation of the heart chambers and vessels.

Detailed descriptions of the blood supply of the human atria and of the interventricular septum have been published.[1, 2] These regions embrace all but the terminal portion of the human cardiac conduction system.

To demonstrate how blood supply to conduction centers may be disturbed during cardiac surgery, four surgical procedures in current use will be discussed. These particular procedures were chosen because they involve different areas of the heart and, by understanding coronary topography in relation to them, one can anticipate the problems of other surgical procedures in the same areas.

I. THE PURSE-STRING REPAIR FOR MITRAL INSUFFICIENCY[3, 4, 5]

Anteriorly this purse-string suture is tunnelled beneath the left circumflex coronary artery toward the anterior interatrial sulcus, then is inserted into the right atrium. As the suture enters the right atrium, the blood supply to the SA node may be jeopardized in the following fashion. The artery to the SA node (ramus ostii cavae superioris) arises from the proximal left coronary artery (Fig. 1) in 40 per cent of cases and from the right coronary artery (Fig. 2) in 60 per cent. From either origin, this vessel passes behind the aorta

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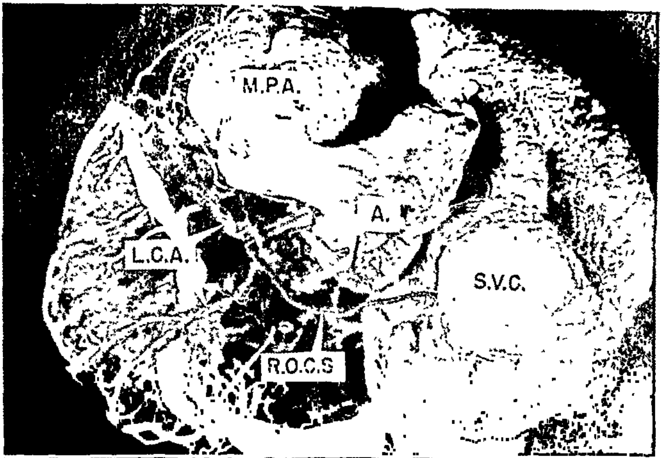
Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

Fig. 1.



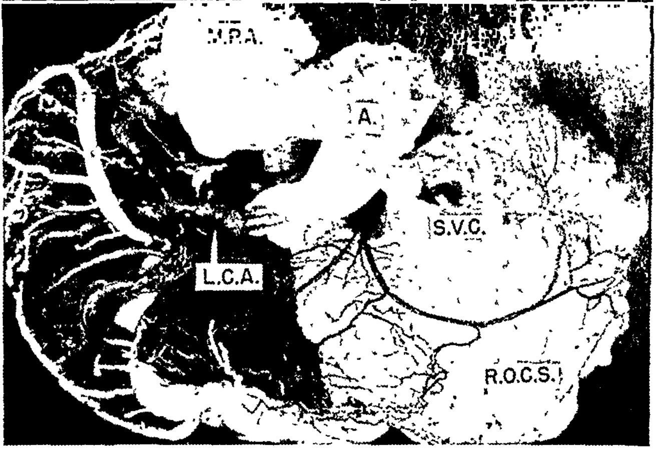


Fig 2.

Fig 1.—Photograph of a cast from a heart in which the ramus ostii cavae superioris (*ROCS*) arises from the left coronary artery (occurs in 40 per cent). White plastic casts the right atrium, the superior vena cava (*SVC*), the main pulmonary artery (*MPA*), and the coronary sinus with the venous branches There is also white plastic in the root of the aorta (*A*) and a bridge of plastic fixing the aortic root to the main pulmonary artery. *LCA* is the left coronary artery. The left atrium and ventricle are not cast. Note how the ramus ostii cavae superioris crosses the region of the interatrial septum anteriorly and encircles the base of the superior vena cava, where it branches to supply the SA node.

Fig 2.—Photograph of a cast from a heart in which the ramus ostii cavae superioris arises from the right coronary artery (occurs in 60 per cent). Casting and identifications are the same as in Fig. 1.

to the anterior interatrial septal groove, ascends to the base of the superior vena cava and encircles this base to supply the SA node.[1] When the suture is passed into the right atrium it may encircle the SA nodal artery, particularly when it arises from the right coronary artery (60 per cent of our cases). As the suture is tightened, the blood supply to the SA node may be occluded. Consequences will depend on collateral supply available to the node, but may include sinus arrest, atrial fibrillation, or other atrial arrhythmias.

Posteriorly, the suture is passed out of the right atrium beneath the coronary sinus to the posterior surface of the left ventricle just below the AV sulcus. There are two hazards at this point. First, the artery to the AV node (ramus septi fibrosi) penetrates the junction of the interatrial and interventricular septa at this location, arising from whichever coronary artery passes the crux of the heart; in 85 per cent of our cases this is the right coronary (Fig. 3). Since the purse string is placed around this artery (Fig. 4), tightening of the suture may occlude the vessel supplying the AV node. The consequence of this occlusion again depends on collateral supply available, but disturbances in AV conduction such as complete or incomplete block may develop.

The second danger at this location (the crux) is to the posterior descending coronary artery, which frequently makes a deep U-turn beneath the posterior interventricular vein just before it descends in the interventricular groove (Figs. 3 and 4). At the apex of this U-turn the AV node artery usually arises. In addition to the AV node artery, this loop of the posterior descending coronary artery which is not visible on the surface may be occluded when the purse-string suture is passed beneath the coronry sinus. Consequences of such an occlusion may be posterior myocardial infarction, the size governed by the extent of collateral circulation available.

Completion of the purse-string suture anteriorly is guided by the location of the straight branches of the left circumflex coronary artery, with the suture being passed beneath each of these, most of which are visible in the epicardium.

II. THE CIRCUMCLUSION TECHNIQUE FOR CLOSURE OF INTERATRIAL SEPTAL DEFECTS[6, 7, 8]

In this operation, a suture is passed within the base of the interatrial septum, entering the septum by passing above the right coronary artery and behind the aorta and emerging posteriorly above the coronary sinus (Fig. 5). As a supplementary maneuver, the top of the interatrial septum is divided as deeply as possible in a sort of cleavage into the septum for the purpose of freeing the neighboring superior vena cava and medial pulmonary veins from traction when the circumclusion suture is brought together over the top of the heart and tightened. In his description of this cleavage of the upper septum, Sondergaard[8] calls attention to a small vessel just in front of the right medial pulmonary vein which must be severed, but states that there is otherwise no bleeding.

Some of the problems of the circumclusion procedure in regard to the coronary arteries are apparent from the previous discussion of the mitral purse string. The cleavage of the upper interatrial septum will almost certainly

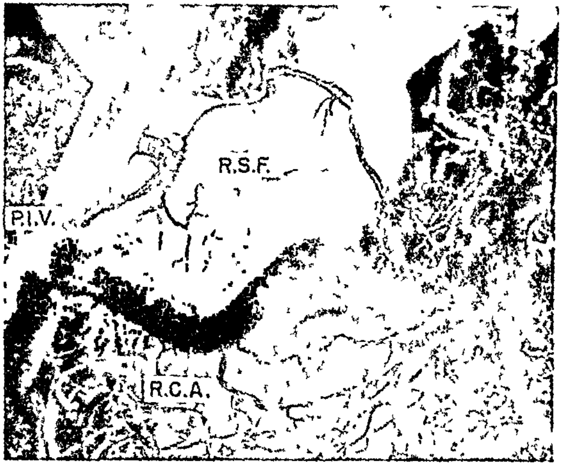


Fig 3.—Photograph of a cast of the right coronary artery, its U turn and the branch to the AV node. White material in the background is a cast of the left atrium (*above*) and the left ventricle (*below*). The right coronary (*RCA*) curves in the foreground then makes a U-turn deep to the posterior interventricular vein (*PIV*) which is cannulated. At the apex of the right coronary loop the branch to the AV node, ramus septi fibrosi (*RSF*), arises.

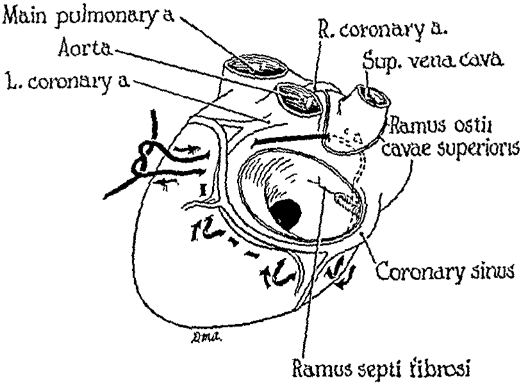


Fig 4.—Diagram of the mitral purse string operation for repair of mitral insufficiency. Note how the suture may damage the arteries to the SA node (ramus ostii cavae superioris) or the AV node (ramus septi fibrosi). See text for discussion.

compromise the blood supply to the SA node (Figs. 1, 2, and 5) and, indeed, the vessel which Sondergaard calls attention to as a bleeding hazard is very likely the ramus ostii cavae superioris which supplies that node. The artery to the SA node also is endangered anteriorly when the circumclusion suture is passed into the base of the interatrial septum.

The artery to the AV node and the upper course of the posterior descending coronary artery (Figs. 3 and 5) are jeopardized posteriorly, both by the passage of the suture in the base of the interatrial septum and by traction when the circumclusion is completed.

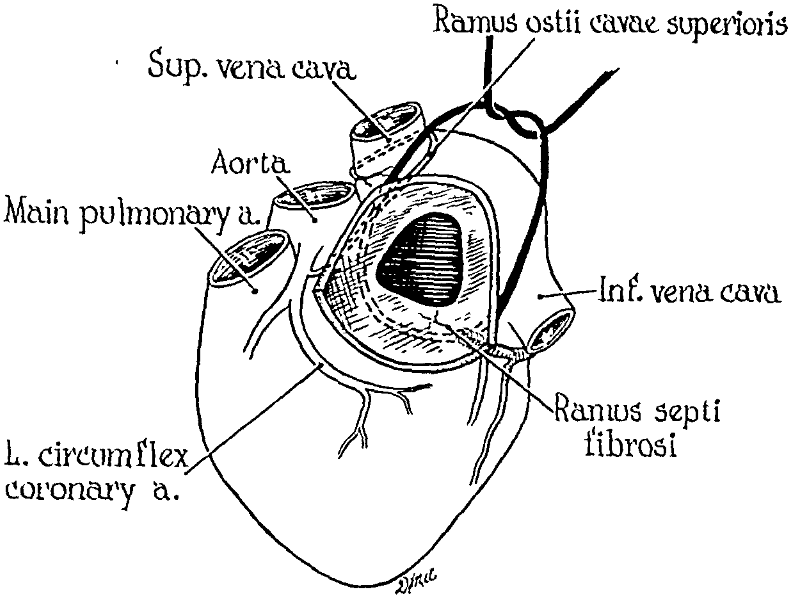


Fig. 5.—Diagram of the circumclusion operation for closure of interatrial septal defects. The arteries to both the SA and AV nodes may be jeopardized (discussed in text).

In addition to the arteries supplying the two nodes, circumclusion encounters a unique bleeding hazard in the lower interatrial septum. The loose areolar connective tissue in this region, through which probe dissection is physically simple, is full of thin-walled Thebesian veins and sinuses. These communicate with the interior of the right atrium.[1] They may be disrupted as the suture is placed, and even more widely opened when it is tightened for the purpose of circumclusion.

III. CANNULATION OF THE VENAE CAVAE FOR TOTAL CARDIAC BYPASS

These cannulae are usually inserted through the atrial appendage or the lateral wall of the right atrium and passed into the venae cavae, where they are secured by tapes (Fig. 6). The blood supply to the SA node may be disturbed by the tape securing the superior vena caval cannula if it is placed near the base of the vena cava, where the arterial circle supplying the SA node lies (Fig. 7).

IV. RIGHT VENTRICULOTOMY

The upper end of this incision is usually near the level of the pulmonic valve ring (Fig. 8). At this point there is an arterial circle (Vieussens' ring)

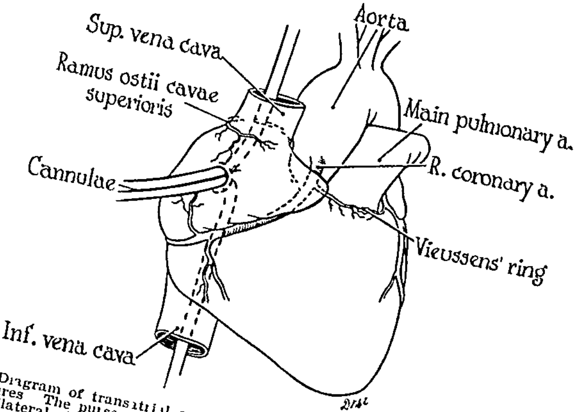


Fig 6.—Diagram of transatrial caval cannulation such as may be employed in cardiac bypass procedures. The purse string incision in the atrial wall may disrupt one of the major channels of collateral circulation to the SA node (from the right intermediate atrial artery). More important, the tape to secure the superior vena caval cannula may be tightened around the ramus ostii cavae superioris arterial circle which supplies the SA node.

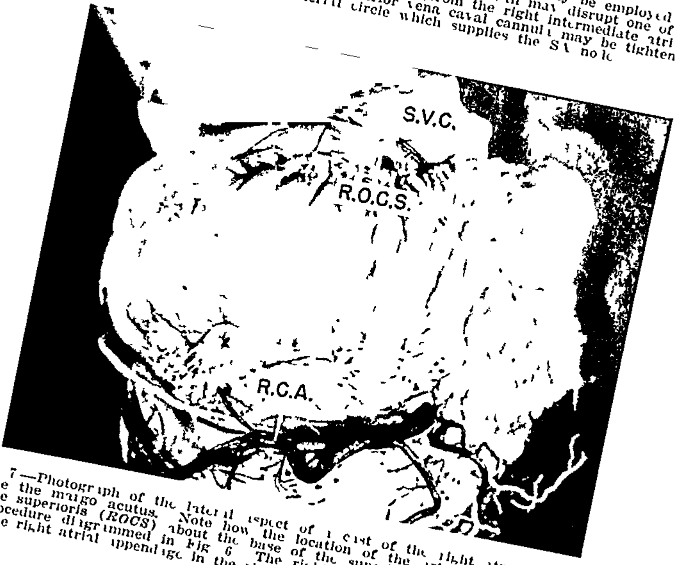


Fig 7.—Photograph of the lateral aspect of a cast of the right atrium, viewed from st above the margo acutus. Note how the location of the arterial circle of the ramus tii cavae superioris (*ROCS*) about the base of the superior vena cava (*SVC*) exposes it the procedure diagrammed in Fig 6. The right coronary artery (*RCA*) emerges from neath the right atrial appendage in the right half of the photograph.

compromise the blood supply to the SA node (Figs. 1, 2, and 5) and, indeed, the vessel which Sondergaard calls attention to as a bleeding hazard is very likely the ramus ostii cavae superioris which supplies that node. The artery to the SA node also is endangered anteriorly when the circumclusion suture is passed into the base of the interatrial septum.

The artery to the AV node and the upper course of the posterior descending coronary artery (Figs. 3 and 5) are jeopardized posteriorly, both by the passage of the suture in the base of the interatrial septum and by traction when the circumclusion is completed.

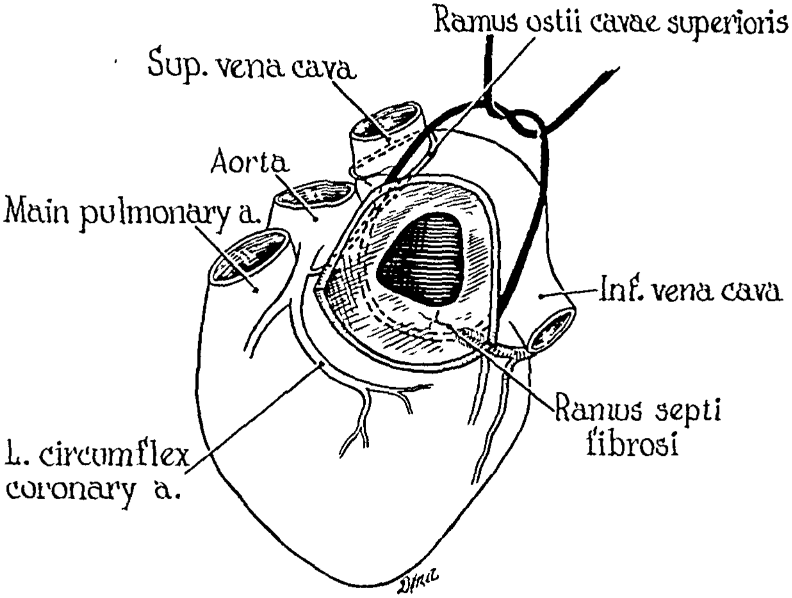


Fig. 5.—Diagram of the circumclusion operation for closure of interatrial septal defects. The arteries to both the SA and AV nodes may be jeopardized (discussed in text).

In addition to the arteries supplying the two nodes, circumclusion encounters a unique bleeding hazard in the lower interatrial septum. The loose areolar connective tissue in this region, through which probe dissection is physically simple, is full of thin-walled Thebesian veins and sinuses. These communicate with the interior of the right atrium.[1] They may be disrupted as the suture is placed, and even more widely opened when it is tightened for the purpose of circumclusion.

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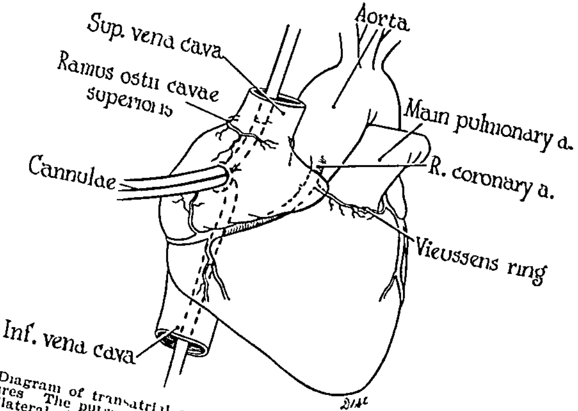

Fig 6.—Diagram of transatrial caval cannulation such as may be employed in bypass procedures. The purse string incision in the atrial wall may disrupt one of the major channels of collateral circulation to the SA node (from the right intermediate atrial artery). More important, the tape to secure the superior vena caval cannula may be tightened around the ramus ostii cavae superioris arterial circle which supplies the SA node.

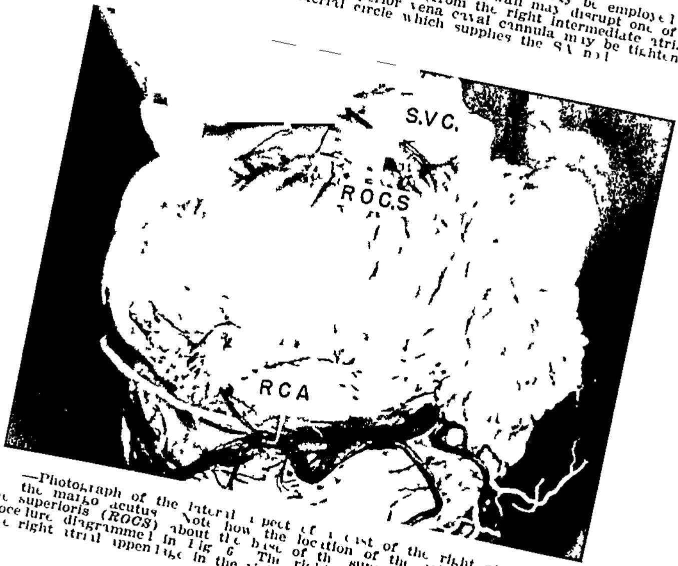

Fig —Photograph of the lateral aspect of a cast of the right atrium viewed from just above the margo acutus. Note how the location of the arterial circle of the ramus ostii cavae superioris (*ROCS*) about the base of the superior vena cava (*SVC*) exposes it to the procedure diagrammed in Fig 6. The right coronary artery (*RCA*) emerges from beneath the right atrial appendage in the right half of the photograph.

connecting the proximal left and right coronary arteries. It is easily identified in the beating heart and whenever possible should be spared because of its importance as a collateral source of flow to either main coronary artery.

The interventricular septum normally lies quite near the free wall of the right ventricular outflow tract (Fig. 8). The arteries of the interventricular septum are predominantly derived from the left anterior descending coronary artery and course posteriorly in a superficial location on the right side of the septum, lying virtually in the right ventricular endocardium.[2] Cutting these arteries in the anterior third of their course may compromise the supply of the distal septal myocardium, as well as the bundle branches of the conduction system.

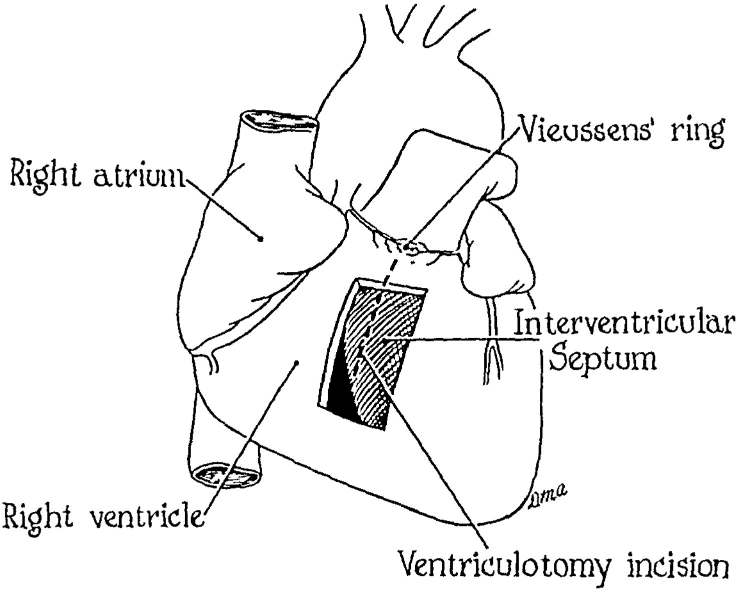

Fig. 8.—Diagram of the incision for right ventriculotomy. The incision should begin below the ring of Vieussens (see text). A window is illustrated in the wall of the right ventricle to expose the underlying interventricular septum, which is in close proximity to the free wall in the region of the pulmonary conus.

DISCUSSION

Consideration of the anatomy of the human coronary arteries suggests that some of the arrhythmias and conduction disturbances encountered in cardiac surgery may be due to impairment of the blood supply of the major conduction centers rather than to damage of the conducting tissue directly. In particular, this may apply to the arteries supplying the SA and AV nodes.

Description of the above hazards is not intended to detract from the surgical procedures discussed, since their merits must be evaluated on many other considerations. It is rather to be hoped that by describing these particular problems all cardiac surgical procedures may be made safer.

SUMMARY

Topography of the human coronary arteries has been discussed by considering it in relation to four surgical procedures in current use. Some of the

arrhythmias and conduction disturbances encountered in these and other operations on the heart may be the result of impairing the blood supply to conduction centers.

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Discussion

DR. PAUL DE CAMP, New Orleans, La.—I want to congratulate Dr. James on the beautiful anatomic study which he has made, and on his careful correlation of it with surgical problems. It is perhaps a commentary on current surgical practice that the surgeon should be so busy operating on beasts and man, so busy making speeches and writing papers that it is necessary for an internist to make such an important anatomic study.

We feel that it is an important concept that cardiac irregularities following operations on or within the heart may be due to interference with the vascular supply to the neuromuscular mechanism rather than necessarily due to direct trauma to the nervous mechanism itself. It would, of course, be characteristic of vascular involvement that in some cases it would be reversible as collateral circulation builds up to compensate for the initial vascular injury. That, of course, is frequent in clinical experience. However, we would like to report one case in which apparently permanent disabling cardiac irregularities developed following an operation in which we suspect the injury to the neuromuscular mechanism was due to involvement of the blood supply. This is the case of a 31 year old man with a large interatrial septal defect. In March of 1956 this defect was closed by the Sondergaard type of purse-string ligature. This purse string was passed through the interatrial supraventricular tunnel and at no time passed through the myocardium itself, so that injury to the A-V node or bundle of His seems extremely unlikely. Beginning promptly, following the operation and continuing to the present, the patient has had a series of disabling mechanical disorders, including auricular fibrillation, supraventricular tachycardia, probably a flutter, auricular flutter with a shifting pacemaker, auricular fibrillation, auricular tachycardia, auricular flutter, and presence of a third pacemaker. These slides demonstrate some of the electrocardiographic abnormalities which have been noted during this period. With vigorous medical management we have been able to control the rate fairly well, but this patient has never been able to go back to work since his operation.

DR. J. C. DAVILA, Philadelphia, Pa.—We have been aware of the fine work of Dr. Burch and Dr. James since their recent publication, and have naturally been most interested in their findings and their description of the coronary blood supply to the atria and to t

S-A node. It is not unlikely that some of these vessels may be injured by some of the procedures performed in these areas. However, the crux of the matter lies in the results which are obtained in these operations, realizing that there are certain structures which, in all types of surgery, must be sacrificed, provided this does not result in serious consequences.

With regard to the mitral purse-string operation, we have seen in our series 8 patients with postoperative atrioventricular dissociation, 2 of which had preoperative suggestion of partial A-V block. All but one of these 8 patients have reverted to their preoperative rhythm within the first 2 to 4 weeks following surgery. Whether this incidence of conduction defect can be attributed to injury to the blood supply of the S-A node by the surgical operation is certainly a moot question.

In some 20 cases of interatrial septal defect of the ostium secundum type, in which we have operated by the Sondergaard method, we have not seen any arrhythmias which we would attribute to surgery. In one patient there was paroxysmal ventricular tachycardia preoperatively, manifesting itself in frequent short bursts of ventricular activity. Following surgery, this patient's episodes of ventricular tachycardia became no less frequent but tended to persist a little longer. After several such bouts within the first 48 hours following surgery, the patient died when the arrhythmia persisted longer than was tolerable. It was noted at surgery in this patient that we were dealing with an extremely irritable myocardium. Whether the operation performed aggravated the arrhythmia is again a question which we cannot answer.

I should like to congratulate the authors for this excellent presentation.

DR. JAMES (Closing).—I thank the discussers for their interest and comments.

OPEN-HEART SURGERY FOR MITRAL INSUFFICIENCY

Donald B. Effler, M.D., Laurence K. Groves, M.D., William V. Martinez, M.D. (by invitation), and Willem J. Kolff, M.D. (by invitation), Cleveland, Ohio

THE NEED for a direct approach to the mitral valve has long been appreciated and now the advent of open heart surgical techniques that utilize the pump oxygenator has made possible a direct approach to the left atrium and the mitral valve. Constant improvement in Lillehei's[1] original techniques utilizing cross circulation, and the addition of valuable adjuncts, permit unhurried operations within each chamber of the heart. Although the ultimate in the treatment of mitral insufficiency has not been accomplished, it is possible to provide surgical palliation in the majority of patients.

Our interest in mitral insufficiency dates from early attempts to close interatrial septal defects of the ostium primum type. At that time we did not understand the significance of associated mitral insufficiency and, as a result, in four consecutive operations where the defect was completely and successfully closed, left heart failure occurred. In each case, the technical success was accompanied with worsening of the condition, and 3 of the patients ultimately died of cardiac disease. A similar penalty was attached to our first effort to correct congenital mitral regurgitation by direct suture of the thin leaflets: the initial surgical success was destroyed by the sudden fenestration and partial avulsion of the septal leaflet. This painful lesson impressed upon us the important kinetic difference between operations involving the right and the left ventricle. Time, and additional experience, have brought into better focus the over-all problems related to mitral incompetency. It is our belief that most types of mitral insufficiency may be helped by the open approach that utilizes the pump oxygenator. The anticipated degree of success will be directly related to the type of valvular defect and the concomitant myocardial and pulmonary changes that are present.

EXPERIENCE

At this time, utilizing the open-heart technique, 14 patients have been operated upon for correction of mitral insufficiency. As mentioned before, at

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From the Department of Thoracic Surgery and the Department of Artificial Organs, The Cleveland Clinic Foundation and The Frank E. Bunts Educational Institute, Cleveland, Ohio.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

least 4 patients were operated on for correction of septal defects without regard for their coexisting mitral insufficiency; these patients are not included in the above group in whom correction of the mitral valve was attempted.

Incompetency of the mitral valve is produced by a variety of pathologic circumstances that we have grouped according to our findings at the time of surgery.

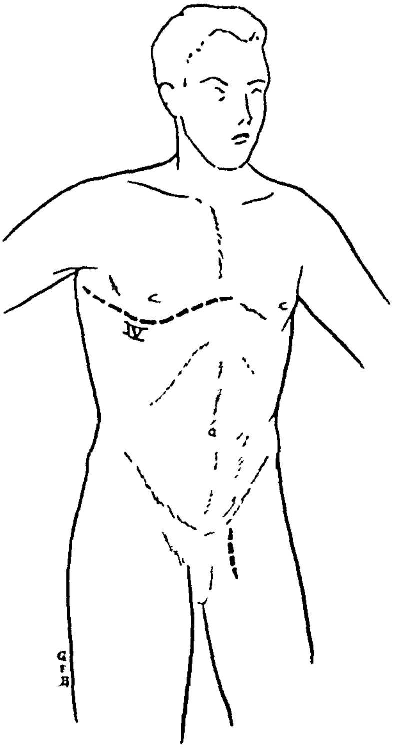

Fig. 1.—Schematic drawing of the right-sided approach to the mitral valve. The anterolateral thoracotomy incision is carried through the right fourth interspace. The sternum will be transsected after division of both internal mammary bundles; the left pleural space will not be entered.

The left common femoral artery is the usual site of retrograde cannulation for arterial return from the pump-oxygenator. The femoral artery is reconstructed after decannulation while the patient is still heparinized.

A. Congenital mitral insufficiency.
B. Acquired mitral insufficiency.
   a. Ruptured chordae tendineae.
   b. Dilatation of the annulus.
   c. Destruction or distortion of the leaflet.
   d. Iatrogenic insufficiency (surgical laceration).

At this stage of operative development, the etiopathogenesis of mitral regurgitation is of less practical importance than are the topographic aspects of the valve itself. Since valvular replacement is not yet feasible, any amelioration of the disease will depend upon the surgeon's ability to make use of what he finds at the site of operation. Hence, the type of regurgitation present, and the anatomic features will have a direct bearing on the surgical outcome.

Every surgeon who employs the routine closed approach for the correction of mitral stenosis will recall the occasional patient in whom was encountered a greater extent of mitral insufficiency than he had anticipated. Now, in such a circumstance, it is the responsibility of the surgeon to perform meticulous digital examination of the valve with predominant insufficiency, in order to evaluate it for a possible direct, open approach.

TECHNIQUE

Approach.—It is our belief that the surgical approach to the mitral valve is best accomplished from the right side (Fig 1) As an elective procedure, the

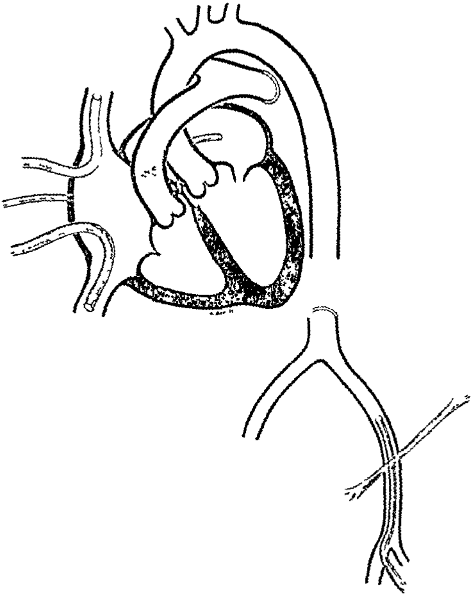

Fig 2.—Cross-section diagram to illustrate the two approaches to the mitral valve from the right pleural space Both routes are available through a right thoracotomy incision. By incising the posterior interatrial groove the left atrium is entered, however, the valvular annulus is not on a direct plane with this portal of entry A more direct approach is obtained by entering the right atrium first and then incising the interatrial septum within the foramen ovalis.

approach from the right permits a unilateral thoracotomy when retrograde femoral cannulation is employed. The advantages of unilateral thoracotomy are self-apparent: retrograde femoral cannulation is an effective method of rendering arterial return from the pump-oxygenator and, in some respects, is superior to the route through the subclavian artery. The actual entry into the left atrium may be accomplished in either of two ways: (1) through the fossa ovalis by way of the right atrium, and (2) through the posterior interatrial groove. There are distinct advantages to each mode of entry. The trans-right-atrial approach offers more direct visualization of the medial commissure, reduces the hazard of postoperative bleeding, permits easier placement of sutures, and allows better control of return to the coronary sinus. The approach via the interatrial groove eliminates entry into the right heart and its attendant problems.

We have successfully performed 3 operations through the left-side approach utilizing a transsternal, bilateral incision with entry through the left atrial appendix. In each case, it was necessary to use elective cardiac arrest in order to rotate the large heart from its normal position. The exposure was fairly adequate, but considerable retraction was necessary before the sutures could be properly placed. It was feared that contained air would be a problem, but it was not. However, the closure of the left auriculotomy, and the replacement of the heart into the normal position put the incisional repair in a posterior position where it was difficult to inspect it for residual bleeding. Although the direct left approach is feasible, even preferable in selected cases, it is our belief that access to the mitral valve from the right side has greater advantages. The left approach is probably preferable for myxoma of the left atrium.

Elective Cardiac Arrest.—Induced cardiac asystole is an accepted adjunct to open-heart surgery.[2-6] Our great enthusiasm for the Melrose technique has been expressed in previous reports. Nevertheless, we are not convinced that it always is necessary or advisable to stop the heart before attempting to correct the incompetent mitral valve. As mentioned by Lillehei,[7] there will be occasions when direct visualization in the beating heart may be particularly helpful in evaluating a diseased mitral valve. It is conceivable that the surgeon may create serious distortion when operating on an arrested flaccid heart, particularly when the repair is confined to the annulus. Although our early efforts were all made in the arrested heart, an effort now is made to work initially with the decompressed, beating heart. If, however, the aortic valve is not competent, the return flow to the open heart will be of such magnitude that cardiac arrest becomes necessary. Usually this can be determined after the patient has been put on total bypass—if the heart visibly becomes decompressed, and palpable pressures decrease accordingly, then asystole will not be necessary. On the other hand, should the heart show little reduction in size and the pressures remain elevated, then cardiac arrest is employed and the quiescent heart is decompressed by direct aspiration.

Left Heart Decompression.—A more recent adjunct to open-heart surgery is the use of left heart decompression by an indwelling catheter in the left atrium. This cannula is inserted from the right side through a stab wound in the right superior pulmonary vein as it enters the left atrium (Fig. 3). This simple addition to the routine system of perfusion cannulation permits a constant pressure recording of the left atrial chamber—more important, it permits prompt venting of the blood should there be a dangerous rise in left heart pressure. Muller, Littlefield, and Dammann[8] have reported on the pulmonary changes attributable to high retrograde pressure in experimental procedures. In a recent report, Kolff and associates recounted our clinical observations in patients who sustained pulmonary damage from high left heart pressures that were transmitted to the pulmonary vascular system. This pulmonary vascular damage is characterized by interstitial hemorrhage, and, on gross examination, is not unlike the picture of blast or compression injury of the lung.

A double purpose is served by the indwelling cannula in the left heart, it decompresses the left heart, and it also permits withdrawal of air from the left atrium. Since trapped air presents an obvious hazard, this additional feature augments the value of this simple safeguard.

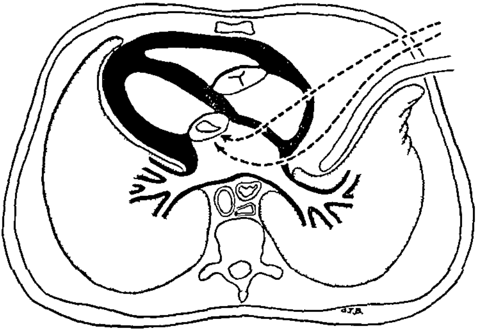

Fig. 3.—Schema of cannulations employed in the open approach to the mitral valve. Three venous cannulae are inserted from the right thorax. 2 cannulae drain the venae cavae in conventional fashion, the third is inserted into the left atrium via the base of the right superior pulmonary vein. This left heart cannula may be used to decompress the left heart, remove trapped air, and measure left atrial pressures.

Retrograde arterial perfusion permits a single thoracotomy approach. The common femoral artery is exposed and after heparinization the cannula is inserted through a small vertical incision. After decannulation the arteriotomy closure is performed while the patient is still heparinized.

Operation.—The patient is prepared for the conventional cardiotomy that utilizes total bypass perfusion. At the Cleveland Clinic Hospital, a disk type of oxygenator (Kay-Cross* modification of the Bjork) is utilized with the roller type of pumps. By direct cutdown the right femoral artery and veins are cannulated for continuous reading of arterial and venous pressures. The electrocardiogram and electroencephalogram are continuously monitored.†

The patient remains in a supine position with the right side of the chest slightly elevated. The incision for anterolateral thoracotomy is made through the fourth interspace, the sternum is transsected, and both internal mammary bundles are divided and are ligated. The left pleural space is not entered deliberately. The pericardium is opened widely and pressures are measured in the chambers and great vessels. Both venae cavae are mobilized, looped by umbilical tape ligatures, and cannulated after heparinization. The left common femoral artery is exposed and is cannulated in a retrograde fashion for the arterial return from the pump-oxygenator. A third cannula is inserted into the left atrium as has been described above. The ascending aorta may be mobilized should elective cardiac arrest be necessary.

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*Manufactured by Pemco, Inc., Cleveland, Ohio.

†With the Monitorscope manufactured by Essential Electric Corpo. Cleveland, Ohio.

When high flow perfusion is established and the caval ligatures are secured, the heart will become decompressed and pressures in both sides will fall to negligible levels. If the heart does not become decompressed satisfactorily, and the left heart pressures remain high, it is to be assumed that the aortic valve is incompetent and that elective cardiac arrest should be employed. When aortic insufficiency is not present, there should be no blood return to the heart except that through the coronary sinus and the bronchial vessels.

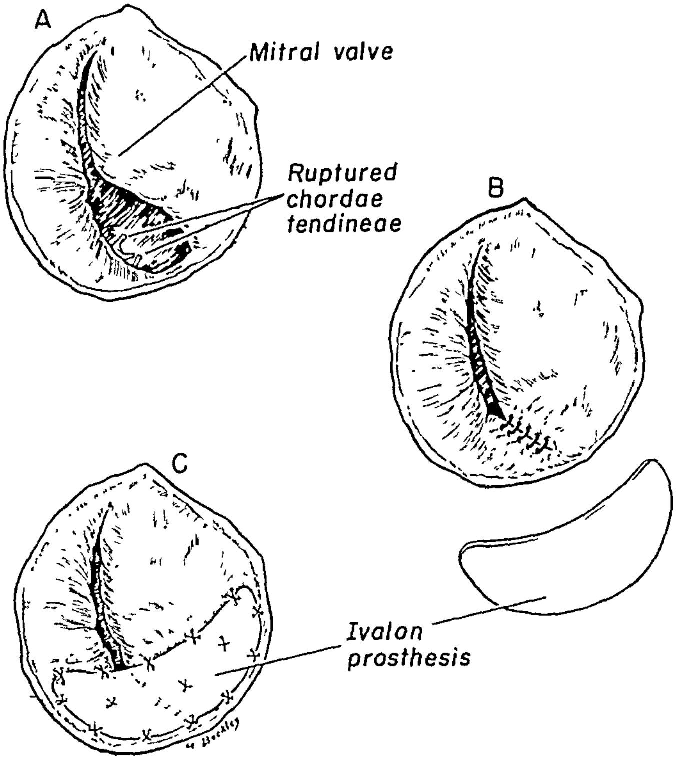


Fig. 4.—Method of correction for flail valve as seen in ruptured chordae tendineae. This method may have special application in iatrogenic insufficiency when chordae tendineae have been surgically transsected.

No effort is made to reapproximate the severed chordae tendineae. The leaflets are approximated over the involved area by direct suture. The valve is then buttressed from the atrial side by a crescent-shaped Ivalon prosthesis that is sutured in place, first to the annulus and then to the underlying valve leaflets. Failure to utilize this reinforcement may be followed by fenestration of the mitral leaflets.

The right atrium is then opened widely and the coronary sinus return is removed by continuous low pressure aspiration; this blood is diverted to the venous side of the pump-oxygenator. Entry to the left atrium is then obtained by an incision in the fossa ovalis—the exposure is adequate and there is little danger of injuring conduction pathways. Blood is aspirated from the left atrium, and the mitral valve is examined under direct vision. The method of

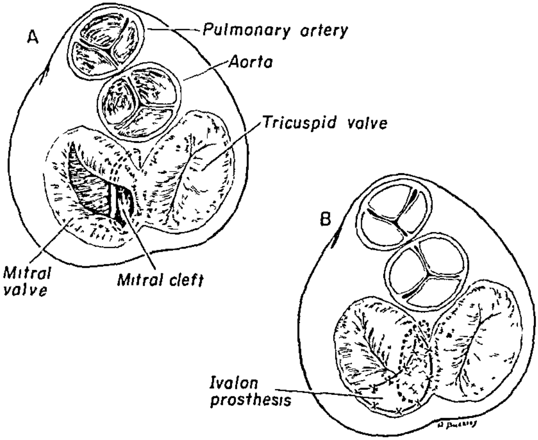
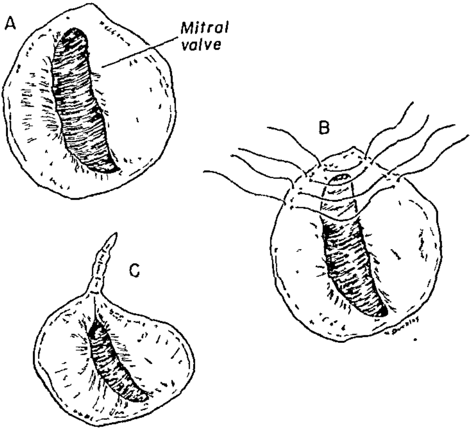


Fig. 5.—Diagram of the approach to the mitral valve through the right atrium In patients with congenital mitral insufficiency related to interatrial septal defects, the right atrial approach permits adequate correction of the incompetent medial commissure, which may be reinforced as described in Fig. 4. The septal defect is then closed with or without prosthetic appliance.

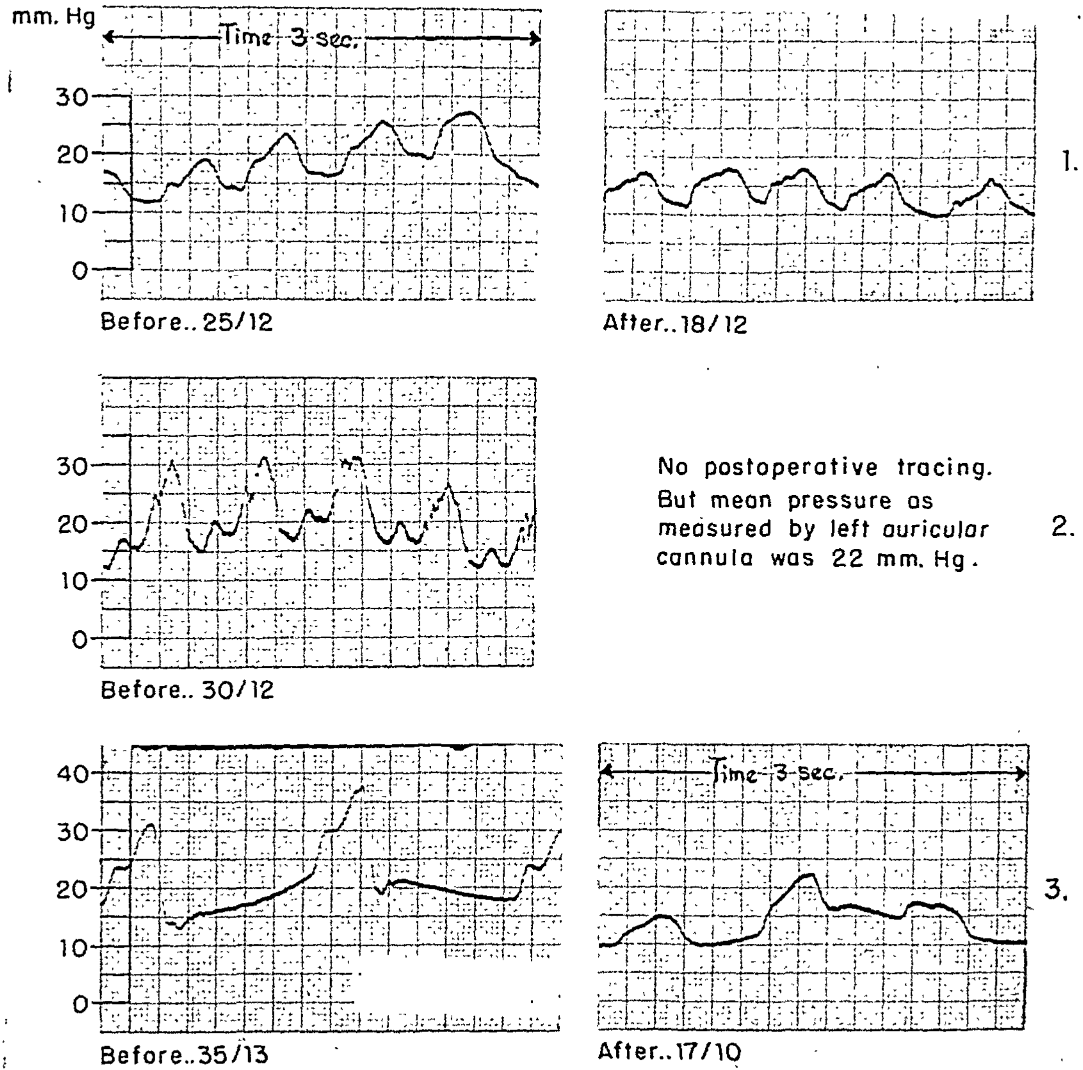
Application of this technique to acquired mitral insufficiency by creating a temporary septal defect in the fossa ovalis has been rewarding. The right-sided approach through the right atrium and the fossa ovalis appears to be the most direct plane to the mitral valve Working through the artificial atrial septal defect permits direct visualization of the entire mitral annulus and both commissures.



number of patients with mitral insufficiency demonstrate only
These patients may not show any stigmata of rheumatic fever. At
appear that application of the annulus over the anterolateral
best palliation. The valve leaflets in such cases are thin and easily
fort is made to close a commissure by direct suture of the leaflet.
lication is accomplished by a series of carefully placed silk sutu

repair is determined after careful inspection of the diseased valve. If any element of stenosis is present, it may be relieved by scissor or knife incision in the involved commissure. Relief of the mitral insufficiency is then undertaken by direct suture of the leaflet or the annulus, with or without a prothesis. The surgeon may work without hurry and with good exposure of the operative field. Although the left atrium is filled with air, the ventricle is dependent in this position and air embolization during the open procedure has not occurred.

Upon completion of the mitral valvuloplasty, the left atrium is allowed to fill with blood before the septal defect is closed by continuous suture. At this



No postoperative tracing. But mean pressure as measured by left auricular cannula was 22 mm. Hg.

Fig. 7.—Pressure recordings on the operating table before and after attempts to correct mitral insufficiency on 6 consecutive patients. (These pressures were recorded by Miss Rose Litturi with a Sanborn strain gauge amplifier, Model No. 140, Serial No. 440, and Statham pressure transducer, Model P23D, 1-75 cm. Hg, Serial No. 295.)

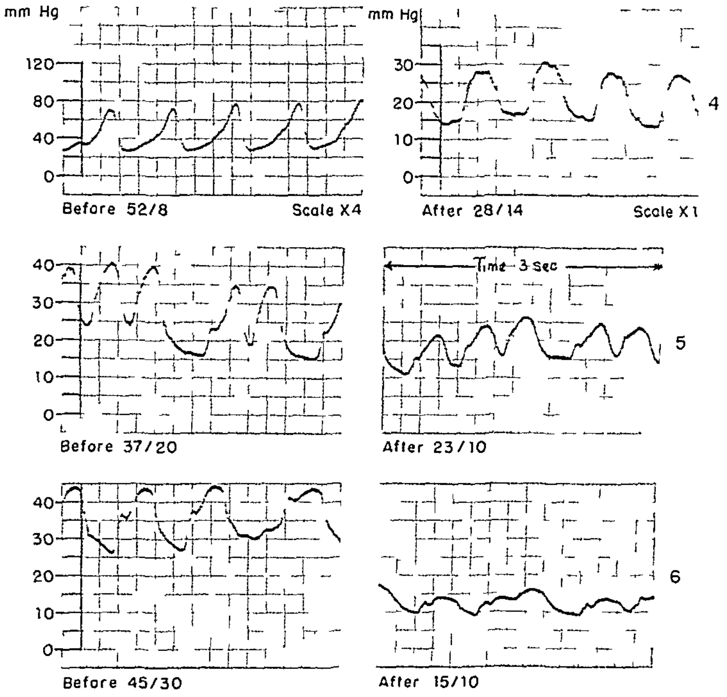
Case 1.—Left atrial pressure was reduced.

Case 2.—This patient had iatrogenic split of one leaflet of the mitral valve plus severance of the chordae tendineae. After the first attempt at open surgical correction, mean pressures in the left atrium were found of 33 mm. Hg. After a second attempt, these fell to 22 mm. Hg. The surgical problem could not be solved.

Case 3.—Left atrial pressures were considerably reduced and the right ventricular pressure was also reduced from 36/2 to 20/7 mm. Hg.

time the indwelling cannula in the left heart is vented with low negative pressure to remove any residual air trapped in it. The right atrial incision is then closed and the caval ligatures are released while the heart is being filled from the right side.

It is our practice to continue the perfusion for 10 minutes or more after the heart has refilled and its beat has returned to a satisfactory rhythm. Since it is possible for a small amount of air to be trapped in the left heart for a number of minutes after the return of an effective heartbeat, the pump oxygenator may be an effective protection against dangerous air embolization. Bubbles released



Before 52/8 After 28/14

Before 37/20 After 23/10

Before 45/30 After 15/10

Fig. —Cont'd. CASE 4.—The left atrial pressures were considerably improved although not reduced to normal. (Note that record before correction is recorded on scale X4.) Disappointing was the high pulmonary artery pressure before (68/44) and after the operation (64/28) indicating advanced pulmonary artery disease. (Patient died 3 weeks later.)

CASE 5.—Also some degree of mitral stenosis. The left atrial pressures as recorded were reduced. The mean left atrial pressures as recorded by the left atrial cannula which were reduced from 12 mm Hg to 8 mm Hg. (The fact that the mean pressures read lower was caused by a slightly higher base line. Also by waiting 10 or 20 minutes the left atrial pressure usually comes down further when the left ventricle has had a chance to recover.)

CASE 6.—Also considerable mitral stenosis. Very gratifying reduction in left atrial pressure after operation. At the same time the pulmonary artery pressure [illegible] down from 60/36 to 10/1; however, one should be careful in one's optimism in these [illegible] as corresponding peripheral arterial pressure during the measuring before [illegible] was between 100 and 130 and afterward was only 80 mm Hg.

from the beating left ventricle can produce disastrous sequelae if they reach the central nervous system. However, air bubbles released during high flow perfusion will be diverted into the coronary circulation. Although ventricular arrhythmia may follow, this is a transient complication and should not affect the ultimate outcome of the operation.

When perfusion has been discontinued, and the patient is maintained by his own heartbeat, pressures again are recorded for each chamber of the heart. If surgical benefit has been accomplished, there should be a significant drop in the left atrial pressure. In cases of severe mitral insufficiency, the pressures of the right ventricle and pulmonary arteries may be unaltered, even though the left atrial pressure has fallen a total of from 15 to 30 mm. Hg. In all probability this is explainable on the basis of fixed arteriolar resistance in the pulmonary vascular bed. In the majority of cases, this pulmonary resistance should gradually subside in response to lasting surgical improvement.

The immediately postoperative care is little different from that of any patient who has had open cardiotomy with total body perfusion. Since we have employed a single thoracotomy, complications usually are restricted to the right side of the chest. The patient should receive the care usually given to any patient who has severe disease of the mitral valve. In addition, of course, the surgical team must attend to the multitudinous details demanded by any operation utilizing perfusion of the entire body.

Results.—Time has not permitted proper evaluation of all patients included in this series. There have been 4 postoperative deaths. The first patient died after surgical fenestration of the mitral valve. The second, a 28-year-old man, who had iatrogenic insufficiency after surgical correction of mitral stenosis, died 6 hours after operation. The cause of death is attributed to diffuse interstitial pulmonary hemorrhages; left heart decompression had not been used. The other 2 patients, both adults with Class IV rheumatic heart disease, died 4 and 6 weeks after operation; congestive failure secondary to irreversible myocardial disease was the cause of death in both patients.

For the surviving patients, benefit has been assessed only by clinical means—none have been subjected to left heart catheterization. Four of these were operated upon more than 1 year ago—each patient has shown benefit by increase in tolerance of exercise and in reduction of the size of the heart.

DISCUSSION

The surgical attack upon mitral regurgitation, as we visualize it now, is palliative in nature. The limited experience and the short follow-up period do not allow proper evaluation of our efforts to date. It is quite unlikely that the measures now employed will prove to be curative in the strict sense. Treatment of an incompetent valve by distortion of the annulus or buttressing of a leaflet can hardly be called ideal. However, the incompetent mitral valve that has suffered the ravages of severe rheumatic fever is a poor subject for an ideal plastic repair. The myocardial and pulmonary damage together with the ugly valve of mitral insufficiency render the prospects of true cure dim indeed.

Nevertheless, an operation that offers quantitative reduction in the degree of insufficiency is of corresponding value. If the surgeon can reduce the systolic pressure of the left atrium by 50 per cent, it is likely that the patient will benefit appreciably. Whether the measures described herein can accomplish this over a long term survival remains to be seen. Furthermore, we have misgivings about the fate of suture material of any type that must be subjected to the fatiguing combination of constant motion and the tension caused by left ventricular pressure. However, one thing is certain, the mitral valve is accessible by open cardiotomy utilizing the pump oxygenator, and the patient with severe mitral insufficiency may tolerate such an operation if immediate benefit ensues.

There is another factor that detracts from the present operation for mitral insufficiency. While the surgeon is working directly on the mitral valve either altering the annulus or reinforcing a leaflet, the extent of repair becomes a matter of judgment and experience. There is no measuring stick that can be used as a therapeutic guide while the heart is open and in a functionless state. Actually the surgeon must wait until the cardiotomy incisions are closed, perfusion has been stopped, and the cardiac function has been restored before he can estimate the degree of success. Even then, success is only partially gauged by the alteration in interatrial pressures after satisfactory rhythm is established. This delay in evaluation is in sharp contradistinction to the closed operation for mitral stenosis, in which the surgeon's index finger accurately assesses alterations in the valve during and after commissurotomy. The digital evaluation is performed within the functioning heart, and guides the surgeon in his decision to pursue the valvulotomy or to terminate the procedure. This type of "evaluate as you go" procedure is not possible in open heart operations for mitral insufficiency.

It would seem that the ideal operation for mitral insufficiency will consist of prosthetic valve replacement. We are encouraged to believe that this will be feasible with the development of better prosthetic devices. Since the exposure already is adequate and the surgeon has ample time, with or without cardiac arrest, the next advance must be a technical one. In other words, the postulated cure of mitral insufficiency will involve a satisfactory valvular replacement that stimulates function of a normal valve.

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(For Discussion, see page 690.)

SURGICAL TREATMENT OF MITRAL INSUFFICIENCY

Earle B. Kay, M.D., Cid Nogueira, M.D. (by invitation), Louis R. Head, M.D. (by invitation), J. P. Coenen, M.D. (by invitation), and H. A. Zimmerman, M.D. (by invitation), Cleveland, Ohio

IT HAS BEEN apparent during the developmental phase of mitral valve surgery that further progress would come only when the mitral valve could be visualized adequately and the various pathologic factors appraised, evaluated, and corrected under direct vision. This phase necessitated the successful adaptation of extracorporeal circulation to left heart lesions. Experience gained from the use of perfusion techniques in the correction of congenital right-sided lesions was beneficial. Additional factors, however, were present, such as the proper approach and exposure, the advisability of elective cardiac arrest, the prevention of air embolism, and the proper surgical techniques. Observations will be presented from the research laboratory, as well as experience gained from the direct-vision correction of mitral valvular disease in 28 patients.

Pathology.—Mitral regurgitation is usually secondary to rheumatic involvement of the mitral valve, but may be congenital in origin. There are two main types of acquired mitral regurgitation—the pure and the mixed. In the *pure form,* the valvular pathologic changes are at a minimum. There may be some thickening of the cusps, some rolling of their edges, and some contraction of the cusps leading to a mild degree of regurgitation. Once the regurgitation has begun, a self-perpetuating set of circumstances tends to worsen the process. Ventricular hypertrophy and later dilatation results from the heart's attempt to compensate for the lessened cardiac output from regurgitation. This in turn leads eventually to further dilatation of the mitral annulus and further regurgitation. The directional flow of blood toward the aortic outflow tract causes a greater degree of widening of the posteromedial commissure and separation of the cusps. The factor of myocardial insufficiency assumes greater importance as the condition worsens.

The *mixed type* is composed of varying degrees of stenosis as well as regurgitation. The other lesions of rheumatic fever are also evident. There is absolute loss of valve substance as a result of the cicatricial contraction of the valve leaflets. There are varying degrees of commissure obliteration giving rise to stenosis. The diseased chordae tendineae may be fibrotic and foreshortened

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dilution curves, and Diodrast studies Although these examinations in skilled hands are not associated with any great degree of complication, they are still formidable and frequently exhausting to the sick cardiac patient, and not infrequently do not provide the desired information Since we now have effective surgical techniques to cope with regurgitant lesions, as well as multivalvular disease, the need for this more precise preoperative information is less important in view of the fact that it can be readily obtained at the time of surgical exploration by pressure studies and direct examination

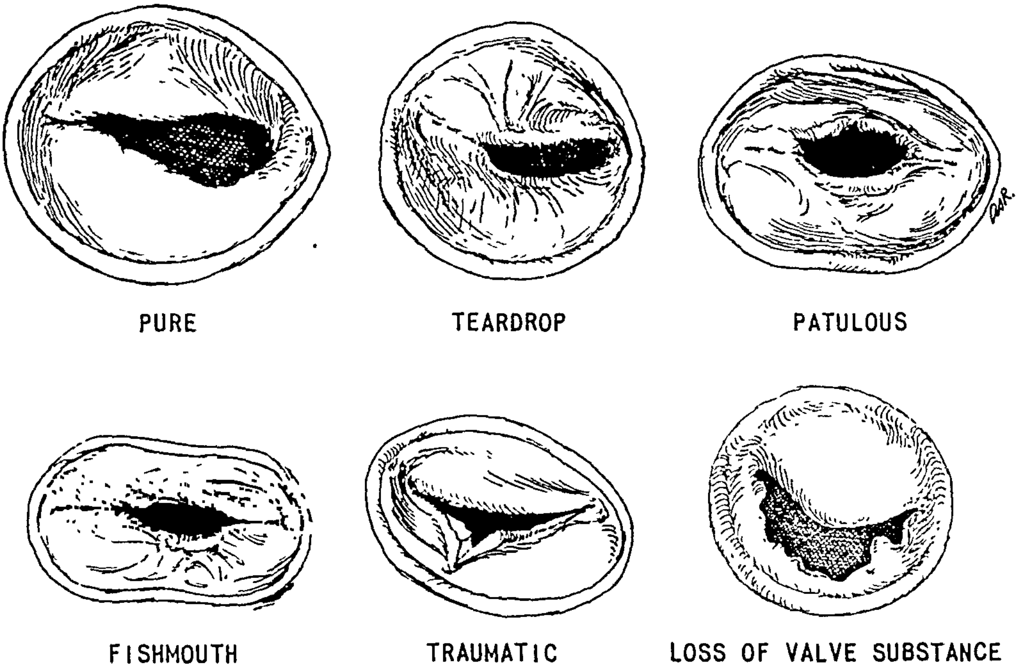
The history, clinical course, and physical examination still remain a very important aspect of the appraisal The electrocardiogram and roentgen examination give valuable information as to chamber hypertrophy and stress It is particularly valuable to have previous studies available for comparison to determine whether significant change or progression of disease has occurred Phonoelectrocardiograms are employed for comparison with postoperative studies A definite improvement in the valve sounds is now being heard, which was a very infrequent occurrence in patients operated upon by closed techniques Right sided cardiac catheterization, with and without exercise, a simple and entirely safe technique, is routinely employed to determine the status of and changes in the pulmonary vasculature, as well as providing information regarding cardiac output and reserve

Pulmonary wedge pressure studies obtained at this time not only provide an index as to left atrial pressures but also provide suggestive evidence as to the presence of regurgitation and/or stenosis, or both It is important to determine the presence or absence of rheumatic activity by sedimentation rates and the presence of C reactive proteins A period of observation in the hospital of the temperature and pulse is important Liver and kidney function tests are employed when indicated In some instances, a longer period of observation is necessary to determine the patient's response to definitive therapy in the presence of failure The likelihood of a successful result is not great in a patient showing progressive evidence of cardiac failure while on a strict medical regimen

If the above studies show the patient to be symptomatic, to have an enlarged heart, to have electrocardiographic evidence of left ventricular and atrial hypertrophy, and evidence of pulmonary hypertension which is aggravated by exercise and does not have signs of activity, then operation is recommended particularly, if serial examinations reveal a definite progression in such findings over previous examinations The cardiopulmonary reserve is great in patients with mitral regurgitation—once there is evidence of progression of the above findings, we believe it is unwise to postpone operation to await more urgent indications because of the detrimental effect on the myocardium which may compromise an otherwise successful result

OPERATIVE APPROACH AND EXPOSURE

The mitral valve can be adequately exposed from either the left or right side A left sided exposure was used in four instances and a right sided exposure in twenty four The 4 patients in whom a left sided exposure was used which, in conjunction with the inversion of the leaflets into the ventricular chamber and adherence to the endocardium, causes the valve to have varying degrees of fixation in the open position. Again, in an attempt to compensate for the regurgitant flow of blood, the ventricle undergoes hypertrophy and dilatation, with consequent annular dilatation and aggravation of the pathologic process. All gradations between stenosis and regurgitation may be encountered from being predominant stenosis to predominantly regurgitant. As such, the valve orifice configuration, as noted in Fig. 1, may be teardrop, fishmouth, patulus, or wholly irregular from extensive loss of valve substance. We have been impressed with the greater degree of regurgitation noted visually over that detected by the intracardiac finger. Although the regurgitation takes place most commonly and to the greatest degree at the posteromedial aspect of the valve, it may be general or occur at the anterolateral aspect.


PURE TEARDROP PATULOUS

FISHMOUTH TRAUMATIC LOSS OF VALVE SUBSTANCE

Fig. 1.—Diagrammatic sketch of variations in pathologic process in patients with mitral regurgitation.

Traumatic regurgitation may result from an improperly executed commissurotomy. This was present in 1 patient in this series, in which the patient had undergone a commissurotomy at another hospital 2 years previously and had been worsened by the procedure as a result of an inadvertent incision in the lateral leaflet.

SELECTION OF PATIENTS

In the recent past, prior to an effective technique for the surgical correction of mitral regurgitation, considerable effort was exerted in the selection of patients for valvular surgery, directed at excluding patients with mitral regurgitation and multivalvular disease. Many diagnostic tests were employed to aid in this differentiation, including left-sided cardiac catheterization, Evans blue dye dilution curves, and Diodrast studies. Although these examinations in skilled hands are not associated with any great degree of complication, they are still formidable and frequently exhausting to the sick cardiac patient, and not infrequently do not provide the desired information. Since we now have effective surgical techniques to cope with regurgitant lesions, as well as multivalvular disease, the need for this more precise preoperative information is less important in view of the fact that it can be readily obtained at the time of surgical exploration by pressure studies and direct examination.

The history, clinical course, and physical examination still remain a very important aspect of the appraisal. The electrocardiogram and roentgen examination give valuable information as to chamber hypertrophy and stress. It is particularly valuable to have previous studies available for comparison to determine whether significant change or progression of disease has occurred. Phonoelectrocardiograms are employed for comparison with postoperative studies. A definite improvement in the valve sounds is now being heard, which was a very infrequent occurrence in patients operated upon by closed techniques. Right-sided cardiac catheterization, with and without exercise, a simple and entirely safe technique, is routinely employed to determine the status of and changes in the pulmonary vasculature, as well as providing information regarding cardiac output and reserve.

Pulmonary wedge pressure studies obtained at this time not only provide an index as to left atrial pressures but also provide suggestive evidence as to the presence of regurgitation and/or stenosis, or both. It is important to determine the presence or absence of rheumatic activity by sedimentation rates and the presence of C-reactive proteins. A period of observation in the hospital of the temperature and pulse is important. Liver and kidney function tests are employed when indicated. In some instances, a longer period of observation is necessary to determine the patient's response to definitive therapy in the presence of failure. The likelihood of a successful result is not great in a patient showing progressive evidence of cardiac failure while on a strict medical regimen.

If the above studies show the patient to be symptomatic, to have an enlarged heart, to have electrocardiographic evidence of left ventricular and atrial hypertrophy, and evidence of pulmonary hypertension which is aggravated by exercise and does not have signs of activity, then operation is recommended, particularly, if serial examinations reveal a definite progression in such findings over previous examinations. The cardiopulmonary reserve is great in patients with mitral regurgitation—once there is evidence of progression of the above findings, we believe it is unwise to postpone operation to await more urgent indications because of the detrimental effect on the myocardium which may compromise an otherwise successful result.

OPERATIVE APPROACH AND EXPOSURE

The mitral valve can be adequately exposed from either the left or right side. A left-sided exposure was used in four instances and a right-sided exposure in twenty-four. The 4 patients in whom a left-sided exposure was used had only a small area of left auricle presenting on the right side. It was felt initially that this might limit the length of the incision in the auricle and in turn impair visibility if the mitral valve were to be exposed from the right side in such instances. Subsequently, it has been found that an adequate exposure can be obtained from the right side in spite of the amount of left auricular wall presenting into the right hemithorax.

A right anterolateral incision with splitting the sternum and with the right shoulder elevated 20 to 30 degrees, was used in twenty-one instances and a posterolateral approach in three. We prefer the right-sided anterolateral approach for to us it appears easier and faster. It requires a smaller incision and is associated with less blood loss and operative trauma. A more adequate exposure of the aortic valve is obtained if operative correction of this valve is also required than is possible in a posterolateral approach. Furthermore, in the advent of cardiac arrest or ventricular fibrillation, access to the heart is more readily obtained. Exposure and cannulation of the femoral vessels is easier from this approach than in a posterolateral one in that with us this aspect of the operation proceeds concomitantly with the thoracotomy. If an extreme posterolateral incision is employed, the aortic valve becomes rotated to the left anterolateral aspect of the mitral valve so that there is less room in the ventricular outflow chamber for the collection of air. However, this is felt to be an unimportant aspect in the etiology of air embolism.

ADVISABILITY OF CARDIAC ARREST

Feeling initially that there was greater safety from air embolism with the use of cardiac arrest, this was utilized in the 4 patients operated upon from the left side and in the first 3 patients operated with the right-sided approach. In one instance, in which a left-sided approach was employed, evidence of transitory cerebral air embolism was noted postoperatively. We do not feel that the use of elective cardiac arrest is a factor in the prevention or etiology of air embolism if the other precautionary measures are employed.

To correct mitral insufficiency surgically the surgeon must have a knowledge not only of the structural changes present but also of the relationship between structural changes and functional changes. Functional changes in the case of valvular disease means motion—the proper opening and closing of the valve. Nothing short of observing the valve mechanism in the beating heart will allow the surgeon information as to the pathologic physiology of that patient's valvular mechanism. With the heart beating, the factors contributing to the regurgitation can be properly assessed and evaluated; the location of the regurgitation—by no means constant—can be determined and the effectiveness of the correction noted. In several instances, annular plication at one site distorted calcified valves so that regurgitation occurred elsewhere. In such instances, visualization of this regurgitation in the beating heart allowed further repair and obviated a partial or poor result.

Other advantages of allowing the heart to beat are that such operations need not be hurried. The impaired myocardium is kept well oxygenated and there is no danger of the occasional difficulty in restarting the heart which may be encountered in patients in whom the myocardial reserve is poor and which may be harmed further by the detrimental effects of potassium or anoxia. There has been no apparent harm resulting from the use of temporary or intermittent aortic occlusion if employed during the procedure to allow a drier field during the initial placement of the sutures in the event of considerable aortic and ventricular regurgitation.

AIR EMBOLISM

Laboratory experience showed us that the mitral valve could be approached from the right side, with the heart beating, without a high incidence of air embolism. Also, there had been no evidence of air embolism in our clinical experience in patients with atrial septal defects, atrioventricularis communis, and transposition of the great vessels, corrected by atrial septal transplantation. These patients were also positioned in a similar manner with the right side of the body elevated approximately 20 to 30 degrees with the opening in the auricle higher than the mitral valve.

In spite of the above, 1 patient approached from the left side with cardiac arrest, and 3 patients approached from the right side allowing the heart to beat, had evidence of air embolism postoperatively. Two of these patients had a right anterolateral incision and the third a right posterolateral incision. Three of the 4 patients had primarily stenotic rather than regurgitant valves. The 1 approached from the left side was primarily regurgitant. In 1 patient the escape of air into the aorta was apparent even before the blood in the auricle was entirely aspirated and the valve visualized. Two successive ventricular diastoles sucked the auricle not only dry of its blood content but also sucked in air. In such instances, the resistance of the stenosed mitral valve may be greater than the systemic pressure against the aortic valve which, in the presence of a forceful ventricular contraction, may allow the ventricle to pump air and foam into the aorta. Evidence of air embolism was not encountered in patients having predominant mitral regurgitation, except for the 1 noted above. Because of these incidents of air embolism, the problem was again studied in the laboratory.

Previously in our laboratory work, evidence of air embolism was noted only at the conclusion of the operation and the particular phase of the operation or technical maneuver, that perhaps caused it, could not, therefore, be assessed properly. A series of experiments were conducted in which a glass tube or bubble trap was inserted into the arch of the aorta or into the [illegible] artery so that the presence of air could be immediately detected (Fig. [illegible] various maneuvers incident to mitral valve correction and [illegible] were then duplicated with the following observations:

1. The mitral valve could be exposed through the left auricle and [illegible] could be emptied of its blood content and no air would [illegible] culation as long as the mitral valve was held [illegible] on pressures were prevented from exceeding aortic [illegible] (Fig. 3). If the aortic valve, however, [illegible]

or by undue tension upon the aortic cusp of the mitral valve, then air occasionally escaped into the aorta, even in the presence of aortic regurgitation. This was not a constant finding.

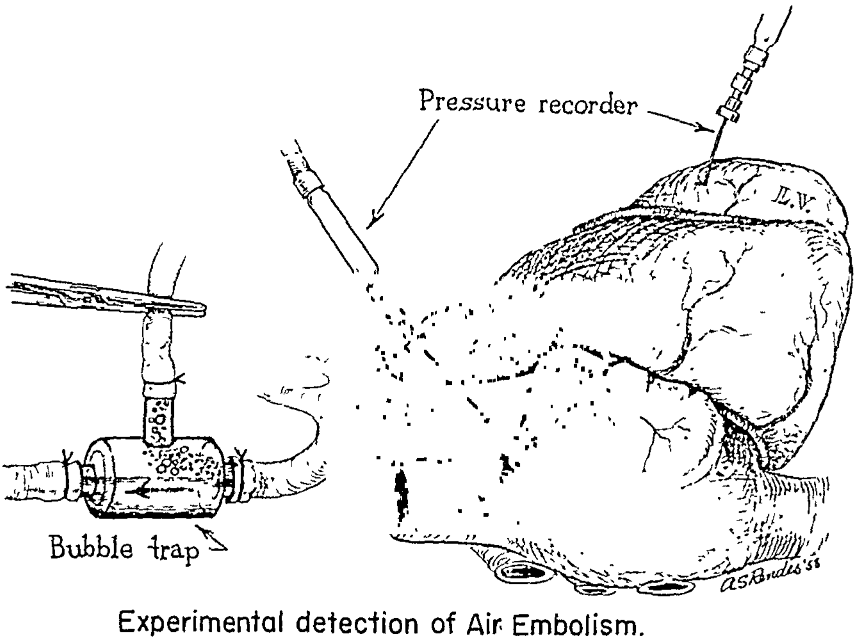


Fig. 2.—Various factors contributing to air embolism detected experimentally by means of bubble trap *in brachiocephalic artery and pressure manometers in aorta and left ventricle.*

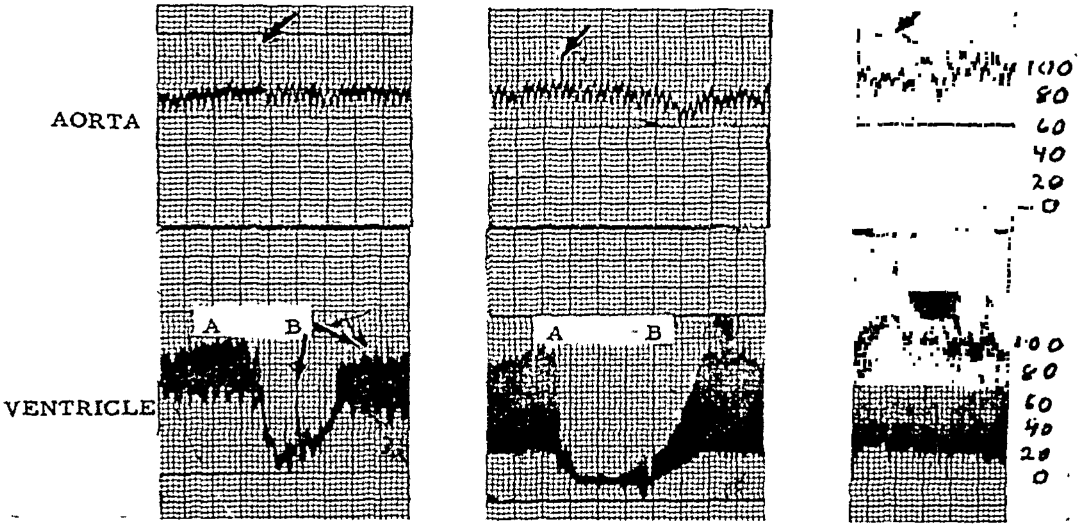


Fig. 3.—Factors Contributing to Air Embolism. Manometer tracing demonstrating absence of air embolism as long as mitral valve is kept partially open so that ventricular systolic pressure never exceeds aortic diastolic perfusion pressure. *A,* Valve closed. *B,* Valve open.

2. A small collection of air could collect in the ventricular outflow chamber adjacent to the aortic cusps which might not be regurgitated into the auricle upon filling. If the ventricle and auricle were allowed to fill with blood for closure without aspirating this air, then, as soon as the mitral valve was allowed to close, the ventricular beat would become effective and this air could escape into the systemic circulation.

3. If the mitral valve was kept open, allowing blood to collect in the ventricular chamber and auricle, foam in the ventricle would be washed back into the auricle. As soon as the air bubble in the ventricle, when present, was aspirated, and the foam had escaped or had been aspirated, the instrument holding the mitral valve open could be removed when the auricle was filled with blood and the auricular incision closed without evidence of air embolism.

4. If the aorta were clamped because of regurgitation, the aortic valve may open and allow air to collect proximal to the clamp. Consequently, such a clamp should be placed close to the aortic valve rather than nearer to the arch to eliminate this potential air space. In case of doubt, one should aspirate the base of the aorta for air while releasing the clamp.

LEFT AURICULOTOMY
PRESSURE RECORDING IN LEFT VENTRICLE AND AORTA

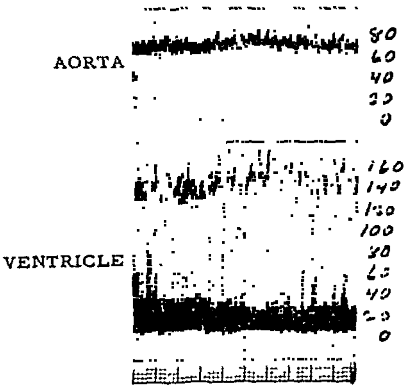


Fig. 4.—Factors Contributing to An Embolism. Manometer tracing demonstrating presence of an embolism when circumstances allow ventricular systolic pressure to exceed aortic perfusion pressure.

5. By simulating mitral stenosis by partially occluding the mitral orifice by suture, keeping the small residual stoma open, or with the mitral valve closed allowing blood to be regurgitated into the ventricular chamber, and with a pressure recorder in the ventricular chamber and aorta, air could escape during the diastolic aortic phase, if the ventricular systolic pressure exceeded the diastolic aortic pressure resulting from a low aortic perfusion pressure or a highly pulsatile type of arterial pump (Fig. 4). Consequently, a high perfusion pressure should be maintained and a nonpulsatile pump, or a pulsatile pump with only minimal phasic differential in pressure, should [illegible] a constant pressure against the aortic valve.

During the surgical correction of mitral insufficiency, the effectiveness of closure of the mitral valve is so inefficient during the early phases of the technique that ventricular systolic pressure can never become great and is easily dissipated in a retrograde direction. As the effectiveness of the correction proceeds, and as the regurgitation lessens, the resistance in the mitral valve may become sufficiently great so as to allow the ventricular systole to push air and foam into the aorta. Consequently, as the mitral valve becomes more competent or as the effectiveness of repair is being evaluated, an area in the valve region that is competent should be kept partially open to prevent the left ventricle from obtaining systolic pressures effective enough to pump air or foam into the systemic circulation. This instrument should keep the mitral valve partially open until the completion of the repair, until all the foam and air have been aspirated from the ventricle, and until the blood has largely filled the auricular chamber.

Three of the 28 patients undergoing direct vision correction of mitral deformities, who had transitory evidence postoperatively of cerebral air embolism, had varying degrees of mitral stenosis. Although the valve was mainly stenosed, a rigid opening or stoma remained through which air and blood could be sucked during ventricular diastole. The resistance of this stenosed valve during ventricular systole was greater than the pressure against the aortic valve, so air and foam were apparently discharged into the systemic circulation. In contradistinction to patients having primarily regurgitation, those with stenosis are more likely to have evidence of air during the initial phase of the operation and this danger continues throughout the period that the mitral valve is exposed prior to the commissurotomy. To minimize this hazard, the mitral valve should first be explored digitally. If significant stenosis is present, it should be partially relieved digitally and an instrument inserted to maintain the valve in an open position before the auricle is emptied of its blood content for completion of the commissurotomy and correction of the regurgitation.

If the auricle is filled with clot, as it was in the three instances, or if the mitral valve is so highly calcified that the danger from calcium embolism from the digital opening is too great, then the aorta should be clamped at its base before these mitral maneuvers are undertaken. As soon as the clots are removed, the commissurotomy performed, and the loose calcium removed from the valve, an instrument can then be inserted to hold the valve leaflets apart; the anesthetist temporarily occludes the common carotids, and the aortic clamp is slowly removed. It is important in such instances that a filter be employed in the sump circuit to avoid embolization through the machine.

TECHNIQUE

A rotating disc oxygenator with a Sigmamotor pump was used initially. Recently a roller pump has been used (Fig. 5). Occasionally, but not routinely, the right auricle is cannulated for coronary sinus blood to return to the machine. Because of the extraordinary amount of blood that may be regurgitated into the auricle even in the presence of a normal aortic valve, it is necessary to have adequate sump facilities to handle as much as 2 to 3 L. of blood if necessary. We have employed two sumps—one with a filter system—to be used in the event of considerable calcium deposits or clot, and the other without. Two bubble traps are available to handle this increased sump load, if necessary.

A flow rate of 50 c.c. per kilogram per minute which results in an arterial inflow of 3 to 4 L. per minute has sufficed to maintain a mean arterial pressure of 70 to 80 mm. Hg. The inflow cannula is always in the common femoral artery through the superficial femoral artery. The venous return to the oxygenator has been by pump suction regulating the venous return by maintaining the vena caval pressure at pre-perfusion levels. This, we feel, gives us a better control over body blood volume. Constant monitoring of the mean arterial pressure, mean vena caval pressure, electrocardiogram, electroencephalogram, pO_2, pCO_2, and pH, body and oxygenator temperature provide us with a constant

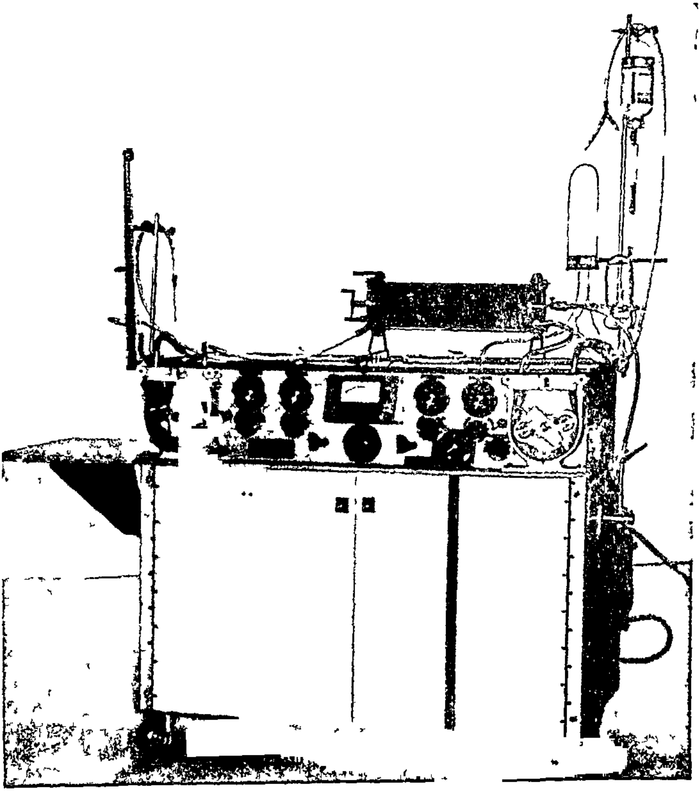


Fig. 5.—Picture of the Kay Cross rotating disc oxygenator used in conjunction with a roller pump mechanism.

physiologic status of the patient. Hematocrit, hemoglobin, and body weight are determined immediately prior to and following surgery. The patient is placed on a heated mattress with the right side elevated between 20 to 30 degrees.

As an anterolateral incision with transection of the sternum is being made, the femoral cannulations for arterial input, arterial manometer, and intravenous infusion are being made simultaneously.

In case of question, the status of the tricuspid valve is determined by digital exploration. Pressure recording of the aorta and left ventricle are then obtained to verify or eliminate coexistent aortic valvular disease. Pressure recordings of the left auricle are then made. The extracorporeal perfusion is then begun while the left auricle is incised and the mitral valve digitally explored. If the mitral valve is obviously incompetent, the sump then empties the left auricle of its blood content so the various factors contributing to the regurgitation can be further visualized and assessed. If a significant degree of stenosis is also present, the valve is opened as widely as possible digitally and an instrument is inserted between the valve leaflets prior to aspirating the blood from the auricle. The commissurotomy is then completed under direct vision. This is followed by visualization of the valve cusps and chordae tendineae. In patients with pure mitral insufficiency, it has been necessary not only to plicate the annulus at both the commissures but also anteriorly and posteriorly (Fig. 6). As the valve becomes more competent, it is important to keep an area of the valve separated to allow regurgitation as other aspects of the valve are being evaluated. Several mattress sutures should be used in the plication of each area so that an adequate apposition of the tissue is forthcoming. The sutures should be without tension.

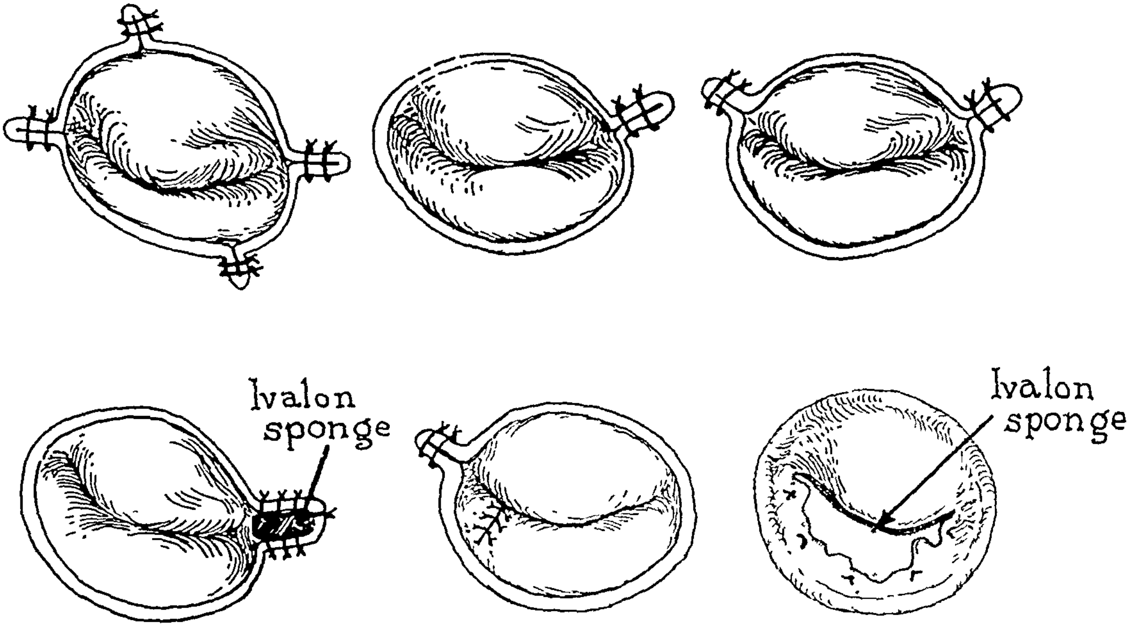


Fig. 6.—Diagrammatic sketch of variations in technique of annular plication and valvular substitutions employed in the surgical correction of mitral insufficiency.

In patients with mixed mitral stenosis and regurgitation, it is important that a complete commissurotomy and valve leaflet mobilization be accomplished prior to correction of the insufficiency for otherwise an extensively calcified commissure prevents, or may prevent, annular approximation of the valve by plication. If a highly calcified commissure or cusp prevents cuspal approximation, the residual opening can be obliterated by incorporating a plug of Ivalon in the plication. Occasionally, it is possible and beneficial to remove the bulk of this calcium prior to the annular plication.

In an occasional patient, one of the mitral cusps—usually the mural—will be so destroyed from the rheumatic involvement as to lack adequate valvular substance. In such instances, valve substitution in the form of a sheet of compressed Ivalon (10 to 2) can be incorporated on the ventricular aspect of the cusp as demonstrated in Fig. 6.

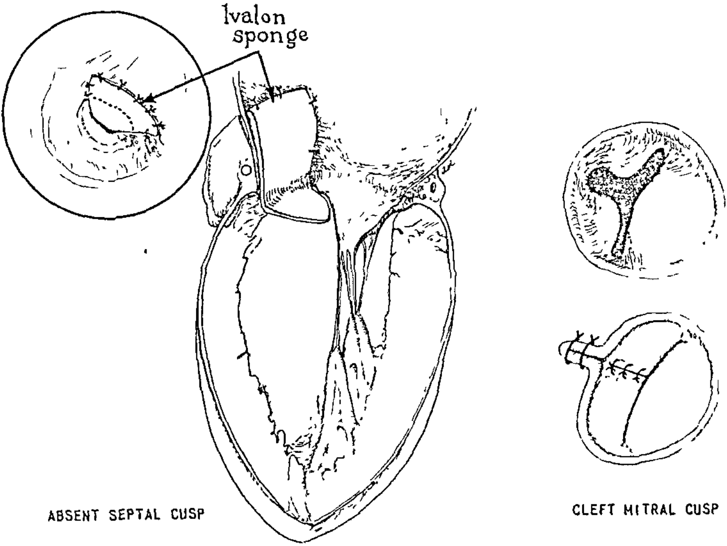


Fig. 7.—Diagrammatic sketch of surgical correction employed in patients with congenital mitral regurgitation associated with atrioventricularis communis.

In 1 patient the regurgitation present resulted from an inadvertent cut into the posterior leaflet below the lateral commissure by a commissurotomy knife during a previous operation at another hospital. Four interrupted mattress silk sutures were employed to sew the torn cusp. A commissurotomy was then performed, followed by an annular plication at the posteromedial commissure. This patient had an excellent result and is completely free from any murmur.

CONGENITAL MITRAL REGURGITATION

Congenital mitral regurgitation is usually associated with atrioventricularis communis. Two forms appear to exist. The more common form is a cleft anterior cusp which is in reality probably the division between the common anterior and posterior atrioventricular cusps of the mitral and tricuspid valves. The other form noted has been the absence of an anterior cusp or the presence of a very rudimentary cusp. The septal aspect of the annular system of both valves may be defective allowing the further dilatation of such valves.

Success of surgical correction is not only dependent upon the closure of the septal defects without tension but the effectiveness with which the valvular incompetence can be corrected. In the event of a bifid or cleft cusp, both the mitral and tricuspid aspects should be approximated by several interrupted sutures. Valvular approximation should also be aided by approximating the anterior and posterior aspects of the annular system at the septal level.

When the septal cusp is so rudimentary as to be entirely ineffective, the closing mechanism of the mitral valve results from closure of the mural leaflet against the ventricular septum. With closure of the septal defect, a shift of the septum to the right results, causing further incompetence of the mitral valve. Competence of this valve in one instance appeared to be effected by fashioning an Ivalon septal cusp in continuity with the Ivalon patch used in closure of the septal defect, as illustrated in Fig. 7.

RESULTS

The incompetent valves in the majority of patients with mitral regurgitation can be surgically corrected by the techniques described. The ease and effectiveness of the correction is largely dependent upon the severity of the pathologic process. Valves composed of severely matted cusps and chordae tendineae, loss of valve substance, or those which are highly calcified, are the most difficult to repair and, short of valve replacement, the surgeon in some instances must be content with a result short of ideal, obtaining as much improvement as possible by the plastic procedure and the addition of the plastic prostheses that are available at the present time. The role of chronic myocarditis, myocardial failure, and the presence of other valvular defects also are important factors in the eventual result. Fortunately, the pathologic process in the majority of the valves is such that they can be corrected and the myocardial reserve is usually sufficiently great as to provide satisfactory function. Fortunately, the number of patients whose process has extended beyond surgical redemption will be few. With continued progress in this field, earlier surgical intervention, and probable lessened severity of the pathologic process from improved therapeutics, greater benefit can be anticipated in the future.

It is too soon to attempt an evaluation of the surgical results obtained in patients with mitral regurgitation corrected by the open technique, for this group have only been operated upon within the past year. However, comparison with the early results obtained previously by closed methods allows for considerable enthusiasm for the open technique at present. The eventual results will be dependent not only upon the effectiveness and permanence of surgical repair, but also upon the myocardial reserve and the reversibility of pulmonary vascular changes. The disease process in the majority of patients was sufficiently severe as to cause left ventricular hypertrophy, left atrial enlargement, severe pulmonary hypertension, and right ventricular hypertrophy With reversal or improvement in the pulmonary vascular changes with further time, greater benefit might be anticipated at a later date

The marked improvement in atrial pressures obtained immediately postoperatively (Table I), the rapidity of the convalescence, the decrease in heart size, and the rapid increase in exercise or work tolerance in the majority of patients following operation, all point to a gratifying eventual result Routine cardiac evaluation studies, including cardiac catheterization are obtained 6 months to 1 year following surgery Time has not allowed the complete performance of these studies as yet

TABLE I MITRAL REGURGITATION

PATIENT	PRESSURE RECORDING LEFT AURICLE (mm Hg)	
	PREOPERATIVE	POSTOPERATIVE
J W	30/25	18/4
V B	68/16	12/4
M L	42/19	22/15
F B	70/22	36/16
C M	60/24	16/7
J P	16/12	4/2
P C	36/20	16/8
S T	26/11	8/4
E H	26/22	10/4
J S	30/17	20/8

There were six deaths in this group, an operative mortality of 20 per cent An analysis of the cause of death in these patients shows that in the future with greater experience some of these deaths can undoubtedly be avoided Failure, in the first patient to be operated upon, was thought to be due to the presence of a severely calcified and destroyed valve, a poor perfusion and a blood imbalance at the end of the operation Two patients died immediately postoperatively from what was felt to be poor myocardial reserve with myocardial failure One patient died from either air or calcium embolism One patient died from an electrolyte imbalance and renal failure This patient had a longer perfusion period than usual due to the inability to maintain a satisfactory cardiac output An atrial septal defect was later found that had not been detected previously As soon as this was closed the heart was then able to maintain a good output The cause of death in the other patient was due to an electrolyte imbalance with retention of fluid, abdominal distention, and pulmonary edema In the future, it is felt that complications due to air embolism can be prevented and those due to electrolyte imbalance largely overcome

COMMENT

It is felt that with the use of a mechanical pump oxygenator, direct vision correction of mitral regurgitation will now be a realization in the majority of such patients The valves in a few patients are so destroyed that nothing short of valve replacement will suffice The operative mortality and morbidity during the developmental phase has been low. Some of the technical factors contributing to this mortality and morbidity are correctable. Others, such as pulmonary vascular changes and poor myocardial reserve, can also be largely avoided by earlier surgical intervention.

SUMMARY

Surgical correction of mitral regurgitation can now be satisfactorily accomplished in the majority of patients with mitral regurgitation. The selection of patients for surgery based on the cardiac evaluation studies is discussed. The aspects of the surgical technique, including the approach and exposure, the advisability of elective cardiac arrest, the prevention of air embolism, and the correction of the incompetent valve are described. Factors contributing to the operative mortality and morbidity, the majority of which can be corrected or prevented, are discussed. The initial results have proved to be exceedingly satisfactory, and, with further experience, should be even more gratifying.

DISCUSSION

(PAPERS BY EFFLER [PAGE 665], KAY [PAGE 677] AND THEIR ASSOCIATES)

DR. H. T. NICHOLS, Philadelphia, Pa.—I have enjoyed the papers of Dr. Effler and Dr. Kay very much. I rise merely to mention our experience with 92 operated cases of mitral insufficiency. The surgical technique has been essentially the same in all cases and was reported to this Association in 1956.

(slide) This illustrates the method of affixing one part of the mitral annulus firmly to the other.

(slide) This shows the sutures tied into position.

The operative mortality by the original closed technique rose subsequently to 27 per cent. We then switched to the open technique in some of the poor risk patients, but lost 4 out of 5 so operated upon.

The majority of the mortality in our patients operated upon by the closed technique seemed to occur during the intracardiac manipulation required in applying the plicating sutures. The cardiac output seemed to be reduced by the surgical maneuvers with resultant decrease in coronary flow leading eventually to cardiac arrest or ventricular fibrillation. More recently, we have employed partial cardiopulmonary bypass with a closed technique in an attempt to get through this most critical part of the operative procedure.

The left thoracotomy approach is used. The uptake catheter to the extracorporeal circulation is inserted into the outflow tract of the right ventricle and the output catheter is inserted into the right femoral artery. We have now operated on 10 patients by this technique with no mortality in the operating room and one late death about 3 weeks postoperatively.

DR. FREDERICK S. CROSS, Cleveland, Ohio.—I would like to compliment Dr. Kay and Dr. Effler on what amounts to pioneer work in this rapidly advancing field. Frequently, the clinical achievements advance so rapidly, however, that we fail to appreciate some of the basic principles involved in a particular surgical problem. I would certainly agree with Dr. Kay that the important considerations in evaluating techniques for open mitral valve surgery are the accessibility of the valve, the incidence of air embolus, and the necessity for adjunct cardiac arrest. We have worked on this problem in the surgical research laboratories at St. Luke's Hospital in Cleveland and our experimental findings have been substantiated by recent clinical experience.

(slide) On looking at the location of the mitral valve superimposed on the cardiac outline, it is noted that this valve is some distance within the heart when approached from the right side This may not be too important when dealing with mitral insufficiency associated with an extremely large left atrium which affords adequate exposure However, in mitral stenosis with a fairly normal left atrium, proper exposure can be a problem When the mitral valve is approached from the left side through a transsternal incision, the operator may be nearer his work but as Dr Effler stated, the valve is still difficult to visualize because of the dependent position of the left atrium Visualization of the valve is made more difficult by the fact that the cardiac apex tends to elevate when the pericardium is opened widely This difficulty can be obviated to a great extent by stopping the heart

(slide) More important than proper exposure, when considering any approach to the mitral valve, is the risk of air embolus from residual trapped in the left ventricle The slide shows how an air bubble might be trapped in the left ventricular outflow tract with the patient in the supine position Without taking special precautions, this air bubble is difficult to remove during or after cardiotomy closure

(slide) The next slide shows the relative position of the cardiac chambers in the various approaches to the mitral valve With the patient supine, the heretofore usual position for open cardiac surgery, it is noted that much of the left ventricle is superior in position to the left atrium affording the possibility for air to be trapped in the left ventricle This potential for the trapping of an air bubble in the left ventricle is present with all of the left sided approaches However, as noted from the slide, this is not true when the mitral valve is approached from the right side All portions of the left ventricle are dependent in position and it is a simple matter to let the left ventricle and left atrium fill with blood prior to the closure of the myocardiotomy By keeping the mitral valve open as the left atrium fills, no air can accumulate in the left ventricular outflow tract It is forced out of the cardiotomy incision placed in the superior position The trapping of air is thus avoided This is true whether or not the heart is approached through the right lateral or the right anterolateral approach In addition, the cannulations for the heart lung bypass are also made from the right side, the other valves are easily approached if necessary and there is the added dividend that adjunct cardiac arrest is not necessary

Experimentally, with the right sided approaches to the mitral valve there was no instance of air embolus Air embolus was a common occurrence however with the left sided approaches, but, it could be prevented by placing a vent connected to suction in the left ventricle during and immediately after closure of the myocardiotomy It would seem then at the present time the right sided approaches to surgery of the mitral valve are the most desirable

DR ARTHUR VINEBERG, Montreal Quebec —A 25 year old theater usher was admitted to the Royal Victoria Hospital on March 8, 1958 He had had fever and joint pains at 9 years of age without other indications of rheumatic fever A second similar episode occurred at 14 years of age Following this he was asymptomatic except for inability to take part in athletics In 1952, he was forced to stop work as a truck driver because of easy fatigability and shortness of breath From this time, exercise tolerance progressively diminished and he was able to work only occasionally

In 1955, he suffered an embolus to the right popliteal artery which did not produce ischemic changes Later the same year he had a cerebral vascular accident with right hemiparesis and aphasia Recovery from this complication was slow but complete He was digitalized on this admission and maintained on digitalis afterward

Physical findings included a blood pressure of 130/75 mm Hg and an irregular apical pulse with a pulse deficit at the wrist There was a marked apical thrust visible on systole The heart was grossly enlarged to the left There was a loud systolic murmur at the apex with radiation to the axilla, accompanied by a thrill There was an aortic diastolic murmur There was no other positive physical findings

X rays (Fig 3, 4) showed marked left ventricular and left auricular enlargement Bullous cysts were visible at both lung bases The electrocardiogram (Fig 1) showed left ventricular hypertrophy with some right ventricular hypertrophy and atrial fibrillation

He was considered to have rheumatic heart disease with predominant mitral insufficiency Right heart catheterization was done There was no indication intracardiac shunt Pressure measurements of interest included the following (

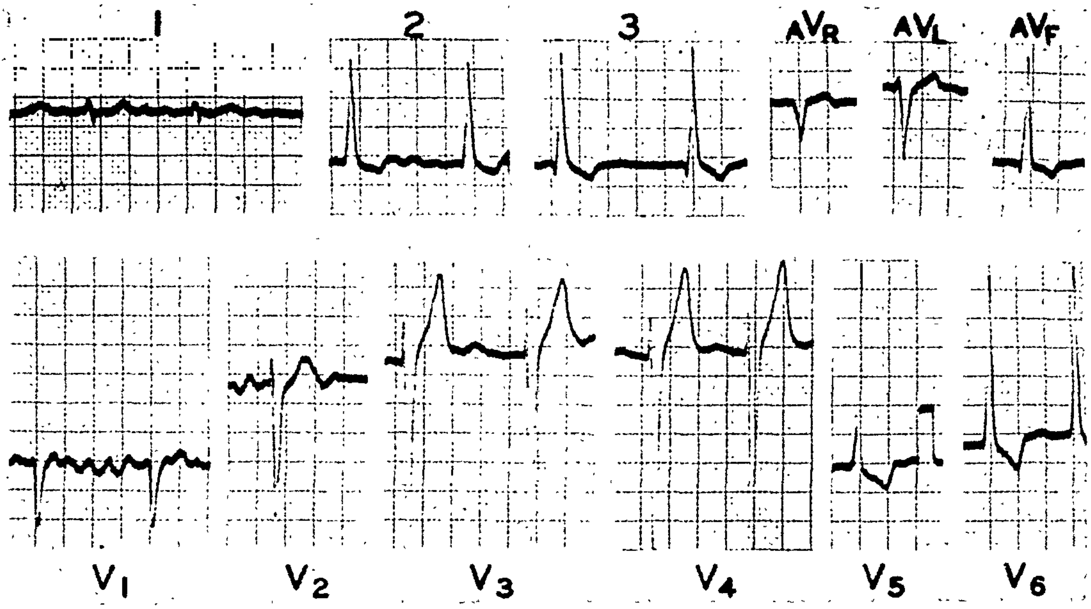


Fig. 1.—Electrocardiogram showing left ventricular hypertrophy with some right ventricular hypertrophy and atrial fibrillation. There was an aortic diastolic murmur.

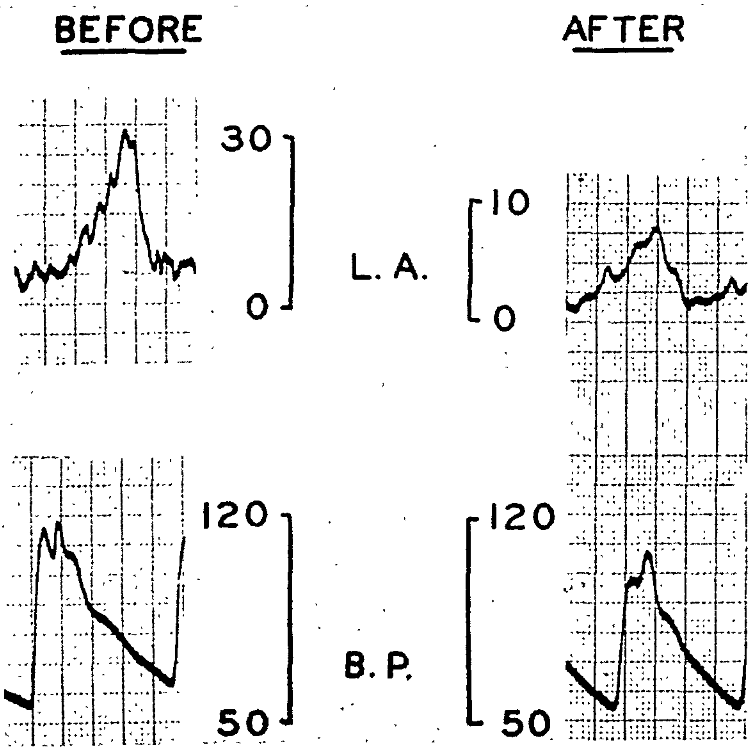


Fig. 2.—Left atrial pressures recorded in millimeters of mercury taken in the operating room before and after mitral annuloplasty which was performed to correct mitral insufficiency (L.B.). Note the marked drop in left atrial pressures after correction of the mitral insufficiency with systemic blood pressures approximately the same.

	Resting	*Light Exercise*
Pulmonary artery	37/18 (25)	65/40 (50)
Pulmonary capillary	20/12 (15)	60/20 (30)

On March 25 mitral annuloplasty was carried out through a right posterolateral thoracotomy The pleural cavity was obliterated by adhesions The pericardium was opened

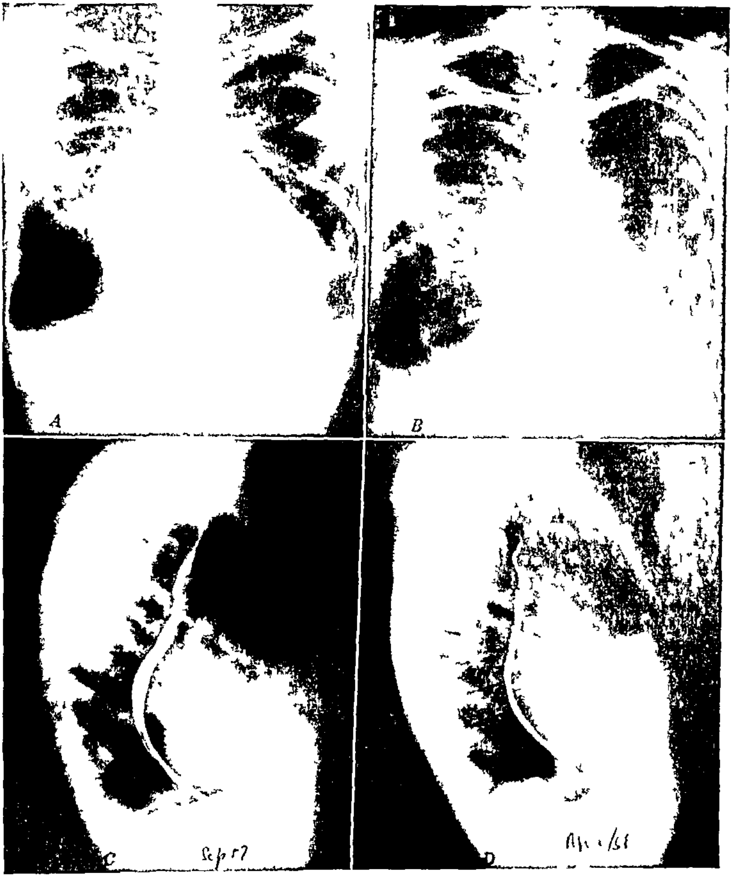


Fig 3.—A A P-A roentgenogram prior to mitral annuloplasty Note the markedly enlarged left atrium and left ventricle also the presence of large lung cysts at both bases

B Shows a P-A film of same patient [illegible] days postoperatively Note the marked decrease in the transverse diameter of the heart which at this stage measured [illegible] cm less than before operation

C A lateral view prior to operation showing left atrium pushing the esophagus posteriorly

D Lateral roentgenogram [illegible] days postoperatively sho[illegible] size of left atrium which has greatly reduced the indentation of the e[illegible] and catheters were inserted into the superior and inferior venae cavae for return of blood to the screen oxygenator. The right femoral artery was cannulated for the return of arterial blood from the pump-oxygenator. Following the institution of extracorporeal circulation, the left atrium, which bulged well over to the right, was incised. The mitral valve was visualized and palpated. The outstanding finding was the great dilation of the annulus into which the palm of a hand could have been placed. Twelve No. 2 silk sutures were placed across the posteromedial aspect of the annulus in order to narrow the annulus to the point where the cusps of the valve could meet. The regurgitant jet, which was marked prior to placing these sutures, was eliminated by them. The left atrial incision was closed with silk sutures.

The bypass was continued for 45 minutes with a mean flow of 3,500 c.c. per minute. Left atrial pressures were taken before and after bypass (Fig. 2) and showed a drop to the normal range with systemic arterial blood pressure at comparable levels.

His postoperative course was marked by a swinging fever in the first week. This returned to normal thereafter without evidence of infection. Blood cultures were negative; otherwise, convalescence has been uncomplicated. There is definite reduction in the apical thrust and the patient himself is much less aware of the pounding of his heart. A systolic murmur remains audible at the apex. The electrocardiogram is unchanged. The x-ray shows 2.6 cm. reduction in heart size. (Fig. 3, *A*, *B*, *C*, *D*.)

The case reported is one of mitral insufficiency treated by open-heart surgery. Reduction in left atrial pressure has been demonstrated. The patient's course since operation has been gratifying.

DR. C. WALTON LILLEHEI, Minneapolis, Minn.—The advent of cardiac bypass techniques has completely changed the outlook for patients with advancing disability due to mitral insufficiency.

In the congenital variety of mitral insufficiency associated with the common atrioventricular canal, recongnition and correction are not difficult. In that regard, I should like to emphasize briefly two important points at some variance from what has been said today. This is based upon experiences with 41 patients operated upon by perfusion techniques since 1954.

First, cardiac arrest is entirely unnecessary in the direct vision repair of these defects, and, in fact, is actually detrimental.

The surgical exposure is excellent through a right atriotomy and, with the ventricles beating, it is far easier to locate accurately the pathology. The clefts in the mitral or tricuspid valves are immediately evident to the eye and their nature can be verified merely by allowing some of the coronary sinus blood to accumulate in the beating ventricles or, if necessary, some 5 per cent glucose can be poured into the ventricle. Other dividends of not arresting the heart are the avoidance of myocardial hypoxia or necrosis and the ability to note and immediately remove stitches obviously interfering with cardiac conduction.

Our second point relates to the method of repairing the clefts in the mitral or tricuspid leaflets. Simple interrupted stitches of fine silk are placed close together between the adjacent halves of the abnormally separated leaflets and are not tied but tagged temporarily with a mosquito forceps until the entire row necessary for the repair has been completed. Then, before tying, a slender strip of Ivalon (2 to 3 mm. wide and 3 to 4 inches long) is trimmed from a block of compressed polyvinyl sponge (5 to 1) and placed between the row of interruped stitches so that the knots can then be tied and seated firmly, but without tension, upon this thin strip of polyvinyl sponge. This results in a snug, blood tight closure upon which the left ventricular thrust is evenly distributed without tissue tension and, in addition, the Ivalon provides a source of reaction that ensures union between the approximated leaflets.

Again, the fact that the ventricles have not been arrested is helpful in evaluating the adequacy of the repair before turning attention to correction of the ostium primum septal defect.

Acquired mitral insufficiency, on the other hand, results from varying combinations of two primary factors: (1) an absolute loss of valve substance from cicatricial retraction and shrinkage of leaflet tissue and/or chordae tendineae, and (2) dilatation of the annulus fibrosus.

One of the very favorable aspects of pure mitral insufficiency lesions has been the consistent finding of relatively good leaflet tissue even in the far advanced lesions. *Calcium, although it may be found often in the left atrial wall opposite the regurgitant jets, is rarely present in the leaflets.* Moreover, the latter, although somewhat thickened and incompetent, remains supple and flexible. These findings are in marked contrast to the usual pathology of the purely stenotic lesions.

It is evident to us that the element of annular dilatation has been greatly overemphasized in the etiology and pathogenesis of pure mitral regurgitation. In 66 per cent of our operated series of patients with pure mitral regurgitation, clinically very severe in most cases and with fantastically enlarged left atria in several, there was no detectable enlargement of the mitral annulus. Thus, in this substantial majority of patients, circumferential purse string constriction carried out blindly or even annular shortening carried out under direct vision, for that matter, would produce stenosis and fail to correct the insufficiency. In these individuals with insufficiency due primarily to loss of substance, the insertion of an artificial prosthesis or artificial leaflet has been the obvious solution for obtaining a good result.

The two basic operative techniques which have been developed for correction of insufficiency, and which we described before this group last year, have not changed appreciably except for refinements based upon greater experience. The mitral valve is visualized by total cardiopulmonary bypass. The standard right posterolateral thoracotomy with the patient in a straight lateral position gives the best exposure to the left atrium and mitral valve. The use of cardiac arrest is contraindicated for the same reasons just mentioned. If there is any element of annular dilatation this is corrected by annuloplasty (shortening of the annulus) as shown in this slide. If instead there is found a significant loss of valve substance (the case in two thirds of our patients), a prosthetic leaflet of plastic has been inserted by direct suture.

As we have seen a greater number of these valves at surgery, we have been impressed with the wide variations in the pathology. For example, it is not uncommon to observe a valve that is incompetent at two or more places but perfectly competent in between. As *a result, certain refinements have come about in the design of our prostheses to suit these* variations. One innovation that we have found of considerable value has been the use of these artificial mitral leaflets.

(slide) They are formed of an inert silicone plastic and come out of the mold after curing looking like this.

(slide) At the time of surgery, with the left atrium opened, the leaflet is then trimmed and tailored with the scissors to correct completely the leakage in the particular patient without interfering with those portions of the leaflets that are still perfectly competent. By means such as this, it has become possible to obtain complete corrections of even very large regurgitant leaks. We are not satisfied with mere palliation, but rather the goal has become the complete restoration of the valvular function to normal.

Moreover, even although many of the 27 patients operated upon to date have had advanced clinical disability (A.H.A. Functional Class III, IV), the operative risk has been low (15 per cent). Not only have the initial gains been sustained but our follow-up, which dates back to 1956, indicates continued improvement in some patients long after the operative procedure. As an example of this, here is the phonocardiogram taken a few days ago of one of our early patients operated upon for mitral insufficiency by open cardiotomy in 1956 (Case 2, J. Thoracic Surg. 35: 154-191, 1958). (slide) You see a completely normal tracing without any murmurs evident now almost 2 years later. Needless to [illegible] clinical improvements in such individuals have been dramatic.

DR. EFFLER (Closing).—Although our enthusiasm for cardiac arrest remains high, we do not believe it is always necessary nor desirable in surgery of the mitral valve. For this reason we do not use it as a routine, but only when an incompetent aortic valve permits blood return of such volume that occlusion of the aorta is mandatory. We believe there is a distinct advantage in visualizing the valve within the beating heart in order to assess the extent and location of the regurgitation.

There is a distinct disadvantage to the open operation for mitral insufficiency at this time. While the surgeon performs his valvuloplasty, utilizing total body perfusion, he has no accurate method of assessing the degree of correction until the operation has been completed and the patient is no longer on the pump-oxygenator run. Some valves are so badly distorted that the surgeon has no way of knowing whether he is actually improving the situation until he has closed his cardiotomy incision, re-established the patient's own cardiac mechanism and then made direct pressure recordings within the left heart. This is quite different from the closed operation for mitral stenosis.

Air embolus has not been a problem with us as yet. We believe that this may be due, in part, to the position of the patient and to the transatrial approach. As we visualize it, this approach with the right side slightly elevated places the left ventricle in a dependent position. Of course, it is still possible to trap air within the left atrium or ventricle and for this reason it is our practice to continue the high flow perfusion for a period of about 10 to 12 minutes. If air has been trapped, it should be extruded in that time and will then appear within the coronary vessels and initiate ventricular arrhythmia. Intracoronary air is a nuisance, but its deleterious effects are transient and easily corrected and it does not have the import of cerebral air embolus.

The fate of the annuloplasty is still of considerable concern to me. It is not hard to visualize these sutures tearing through under the unrelenting impact of the beating left heart. Like Dr. Kay, we have used annuloplasty in those patients whose regurgitation was attributable to dilatation of the annulus. We used this type of procedure simply because we had nothing more to offer the patient and were gratified to find appreciable reduction in the left atrial pressures when the procedure was completed. However, it seems logical to hope that the ultimate operation for mitral insufficiency will be along the lines described by Dr. Lillehei, some form of valve replacement with a practical prosthetic valve.

I appreciate very much this opportunity to appear before the Association.

SATISFACTORY SURGICAL CORRECTION OF PECTUS EXCAVATUM DEFORMITY IN CHILDHOOD

A Limited Opportunity

Kenneth J. Welch, M.D. (by invitation), Boston, Mass.

MATERIAL

One hundred and thirty-eight children with moderate to severe pectus excavatum deformity have been evaluated, from 1951 to 1958, with regard to the desirability of surgical correction and comprise the basis for this report. Seventy-six patients (53 per cent) were considered suitable candidates for operation. There were 49 boys and 27 girls (Fig. 1). The remaining 62 patients (47 per cent), mostly infants, did not have progressive deformity and gave clear-cut evidence of improvement by the twenty-fourth month.

ETIOLOGY

The etiology of pectus excavatum deformity is not clear in many cases. However, it is possible to analyze a number of these deformities.

Only 8 patients had inherited disease. There is little doubt about a congenital element in this problem, in that the deformity is uniformly present in the 32 mm. embryo. In addition, it is always present at birth in those individuals who remain in the progressive or worsening group.

There is a condition known as "spinomyelodysplasia" with structural damage to lower dorsal somites and associated defects of the vertebral column, ribs, and cartilage segments. These patients have the most severe problems in that they not only develop the usual structural alterations of the thoracic cage in pectus excavatum but have superimposed scoliosis (Fig. 2).

Pectus deformity may be acquired with steady pressure against the soft and unossified gladiolus. The term "Zapatero de Torax" is used in Cuba. This describes the acquired funnel chest that occurs in youngsters in the shoemaking trade where a leather cutting instrument is braced forcibly against the lower sternum.

From the Pediatric Surgical Service, Boston City Hospital, and the Department of Surgery, Harvard Medical School, Boston, Mass.

Read at the Thirty-eighth Annual Meeting of [illegible] for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

DR. EFFLER (Closing).—Although our enthusiasm for cardiac arrest remains high, we do not believe it is always necessary nor desirable in surgery of the mitral valve. For this reason we do not use it as a routine, but only when an incompetent aortic valve permits blood return of such volume that occlusion of the aorta is mandatory. We believe there is a distinct advantage in visualizing the valve within the beating heart in order to assess the extent and location of the regurgitation.

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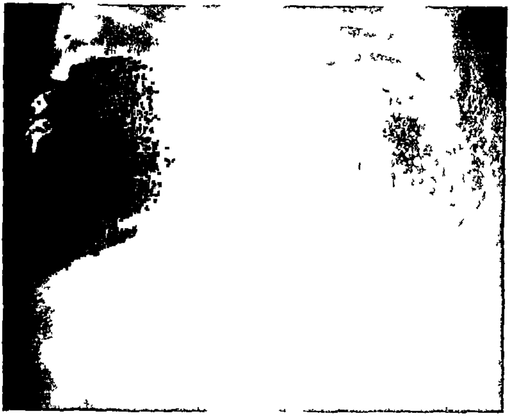

Fig 2—Spinomyelodysplasia and pectus excavatum deformity in patient 8 months of age

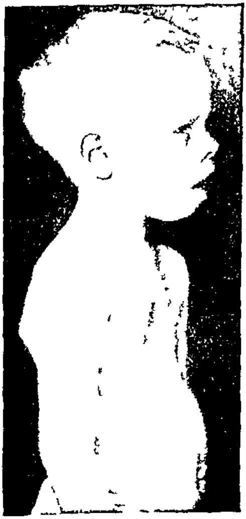

Fig 3—Typical habitus and poor growth performance in a 3 year old boy

Another group is explained by relative inspiratory obstruction. This is most striking in the first year of life and, in our experience, this is the group most likely to remedy itself as the individuals gain greater air inlets. This may be a desperate period for the family. Indeed, 2 youngsters required tracheostomy at the height of bacterial pulmonary infections.

There is no abnormality at the costochondral junction. Longitudinal sections through this zone, after decalcification, show no gross or microscopic alterations. As one studies resected cartilaginous segments, by multiple coronal sections, there is often found a disordered architecture and a situation that implies local circulatory or nutritional damage—a chondodystrophy. Certainly one often encounters very bizarre-shaped cartilage segments in the process of resection.

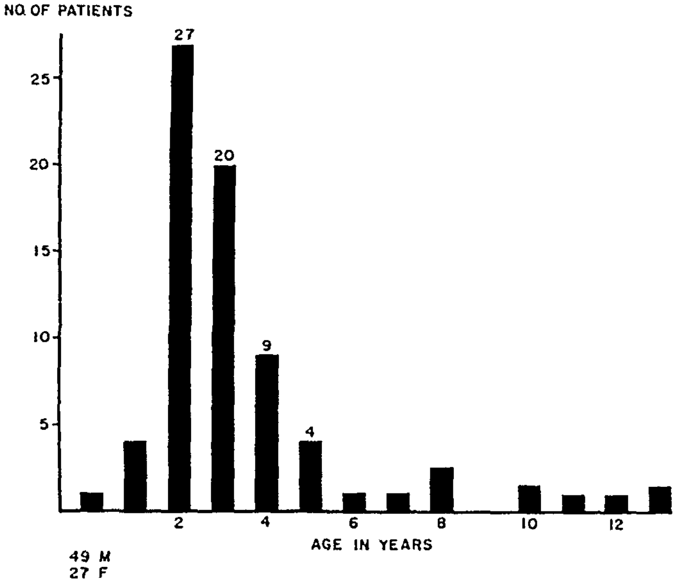

Fig. 1.—Surgical correction of pectus excavatum deformity—76 patients, 1951-1958.

In the group of patients with multiple congenital anomalies, including mental deficiency, there has been an element of hypotonia with poor posture, and the disease may, at times, be the result of complex muscular imbalance.

The concept of a restricting retrosternal ligament, or short central tendon of the diaphragm, has focused attention on the maximal area of deformity and has contributed to the evaluation of this disease.[1] Most writers have accepted this theory and have described fibrous extensions of the linea alba that, when divided, result in a dramatic lift in the central area of the deformity. This has not been confirmed in this series. In the seventy-six operations performed, only loose areolar tissue was encountered behind the xiphoid and there was no significant lifting of the deformity after transection of the xiphoid. It was not until much later in the operation, when all of the deformed cartilage segments had been resected, that one could see a significant structural improvement.

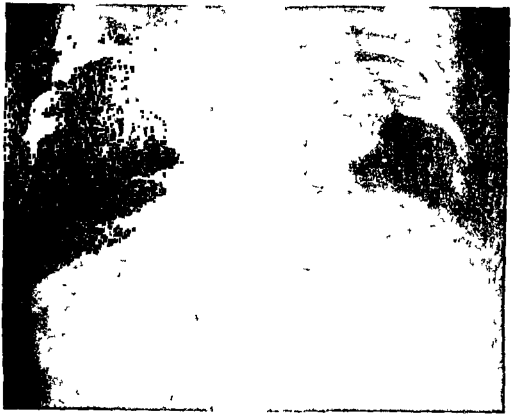

Fig 2 —Spinomyelodysplasia and pectus excavatum deformity in patient 8 months of age

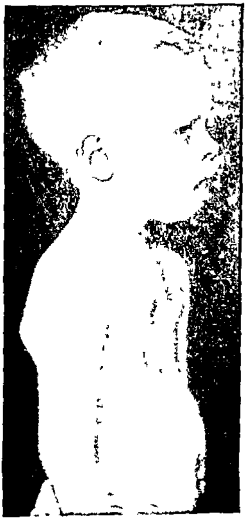

Fig 3 —Typical habitus and poor growth performance in a 3-year-old boy

Another group is explained by relative inspiratory obstruction. This is most striking in the first year of life and, in our experience, this is the group most likely to remedy itself as the individuals gain greater air inlets. This may be a desperate period for the family. Indeed, 2 youngsters required tracheostomy at the height of bacterial pulmonary infections.

There is no abnormality at the costochondral junction. Longitudinal sections through this zone, after decalcification, show no gross or microscopic alterations. As one studies resected cartilaginous segments, by multiple coronal sections, there is often found a disordered architecture and a situation that implies local circulatory or nutritional damage—a chondodystrophy. Certainly one often encounters very bizarre-shaped cartilage segments in the process of resection.

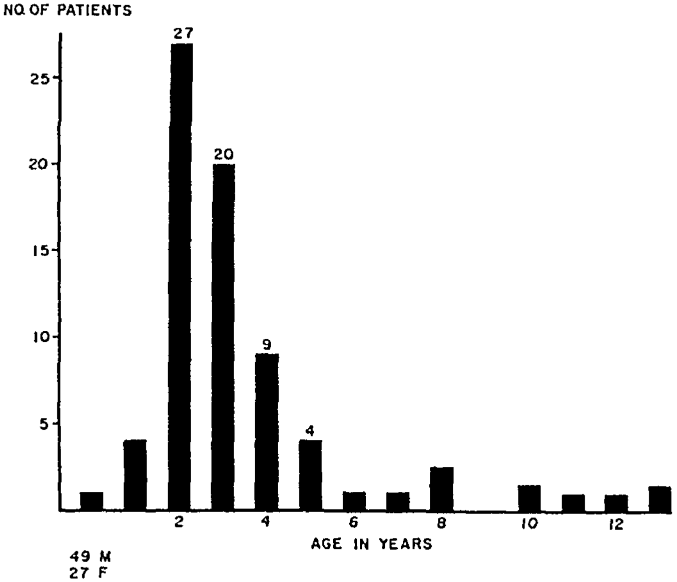

Fig. 1.—Surgical correction of pectus excavatum deformity—76 patients, 1951-1958.

In the group of patients with multiple congenital anomalies, including mental deficiency, there has been an element of hypotonia with poor posture, and the disease may, at times, be the result of complex muscular imbalance.

The concept of a restricting retrosternal ligament, or short central tendon of the diaphragm, has focused attention on the maximal area of deformity and has contributed to the evaluation of this disease.[1] Most writers have accepted this theory and have described fibrous extensions of the linea alba that, when divided, result in a dramatic lift in the central area of the deformity. This has not been confirmed in this series. In the seventy-six operations performed, only loose areolar tissue was encountered behind the xiphoid and there was no significant lifting of the deformity after transection of the xiphoid. It was not until much later in the operation, when all of the deformed cartilage segments had been resected, that one could see a significant structural improvement.

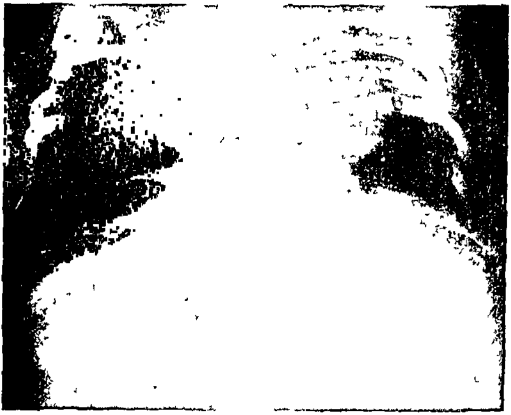

Fig 2 —Spinomyelodysplasia and pectus excavatum deformity in patient 8 months of age

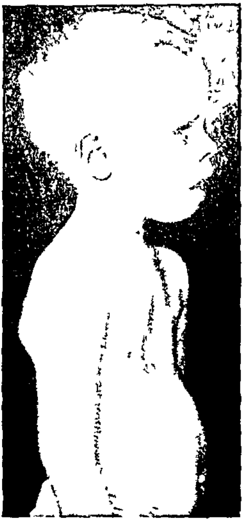

Fig 3 —Typical habitus and poor growth performance in a 3-year-old boy

SYMPTOMS AND SIGNS

Very few patients were symptomatic at the time of operation; however, ll had a history of a difficult first year of life with recurring bronchitis, 'croup,'' and more than the usual number of respiratory infections.

Percentile growth performace was usually in the 50 to 90 per cent range, s plotted on the anthropometric charts of the Children's Medical Center up o the age of 2 years. However, after that we encountered 17 patients who vere in the twenty-fifth percentile or below by the end of the fourth year.)ne Puerto Rican youngster was of unusual interest in that she was hospitalzed three times with an x-ray diagnosis of bronchopneumonia and was in the enth percentile at age 5 years. Two siblings, without this deformity living n the same household, had not had difficulty with respiratory infection and vere in the nintieth percentile. The downward drift in over-all physical de'elopment with severe funnel-chest deformity in this 2-to-5 age group has ecome quite impressive (Fig. 3).

Four youngsters complained of chest pain with activity, and 2 had a resenting complaint of intermittent syncope.

Eleven patients had a short systolic murmur at the left border of the ternum; 1 patient had an associated diastolic murmur. This youngster was n the multiple anomaly group and we rejected her as an operative candidate. Ve have the strong feeling that if there is anything atypical about the nurmur in its location, or if it carries a diastolic component, the risk of operaion goes up greatly. Such patients should not be operated upon without an natomic diagnosis of the cardiac lesion by cardiac catheterization.

SELECTION FOR OPERATION

Our position has been arrived at by a trial and error method extending ver a 7-year period. In the first period (1951 to 1955), age at the time of peration ranged from 8 months to 14 years. One patient was lost at the ge of 16 months—a youngster with multiple congenital anomalies. Shaken y this experience and by the fact that the "limited operation'' was unsucessful in correcting the deformity and required subsequent complete cartilage esection to the angle of Lewis, we have given up operations in the first 2 years f life. Eleven youngsters, more than 6 years of age, were operated upon nd the results in this group were not considered to be as satisfactory as in hose patients operated upon between the ages of 2 and 5 years.[2] We had reater difficulty with the anesthetic management, with the operative technical rocedure, and with the postoperative course. It appears that there is a imited opportunity to obtain complete structural cosmetic and functional orrection of this disease.

We like to see all of these youngsters from birth. Lateral chest films should e obtained at each 6-month interval. Two important measurements are made ı these lateral films which are taken neither in deep inspiration nor in full xpiration. The first measurement is an external skeletal AP diameter of the hest at the angle of Lewis. The second measurement is the distance between the anterior surface of the vertebral body and the gladiolar-xiphoid junction. The normal ratio between these two measurements is one or greater than one. In mild degrees of pectus excavatum deformity, this drops to between 0.75 and 0.5. In moderate deformity there is a ratio of from 0.5 to 0.3. With severe deformity the ratio is 0.3 or below. In several cases, the sternum was in apparent contact with the anterior surface of the vertebral body and a ratio of 0.1 is not unusual (Fig. 4). The significance of this ratio has to be corrected for progressive loss of AP diameter. This occurs in children in the 2- to 5-year age group who, in a matter of months, acquire the typical pectus excavatum

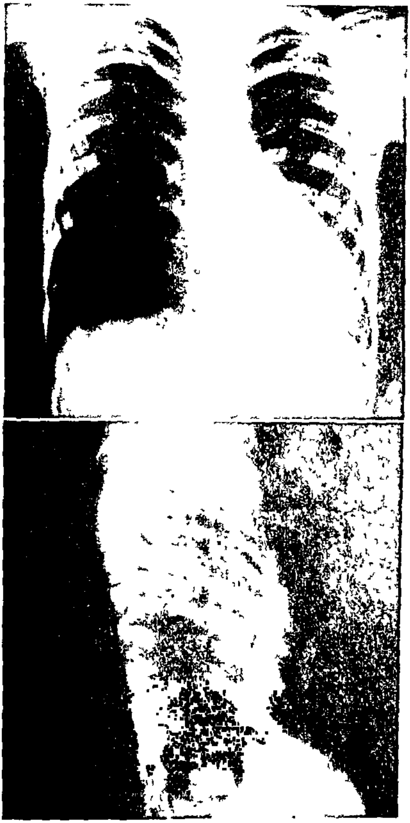

Fig. 4.—Anteroposterior and lateral chest roentgenograms of an 11-year-old boy with severe, irreversible pectus deformity. The sternum is in apparent contact with the vertebral column.

habitus. There is a dorsal kyphos and they slump over the defect. If the youngster's AP diameter is decreasing, and his ratio is constant, we would consider him a candidate for operation with lesser degrees of deformity. In short, in a youngster with a normal AP diameter, we would like to see evidence of an unimproving ratio of 0.5 or less at the end of the second year before recommending him for operation (Fig. 5). It has not been difficult, on this basis, to sort out the 62 individuals that have not required operative interference. Our estimate of improving cases has been accurate and we have obtained several 6-year follow-ups in this group and found normal chest contours.

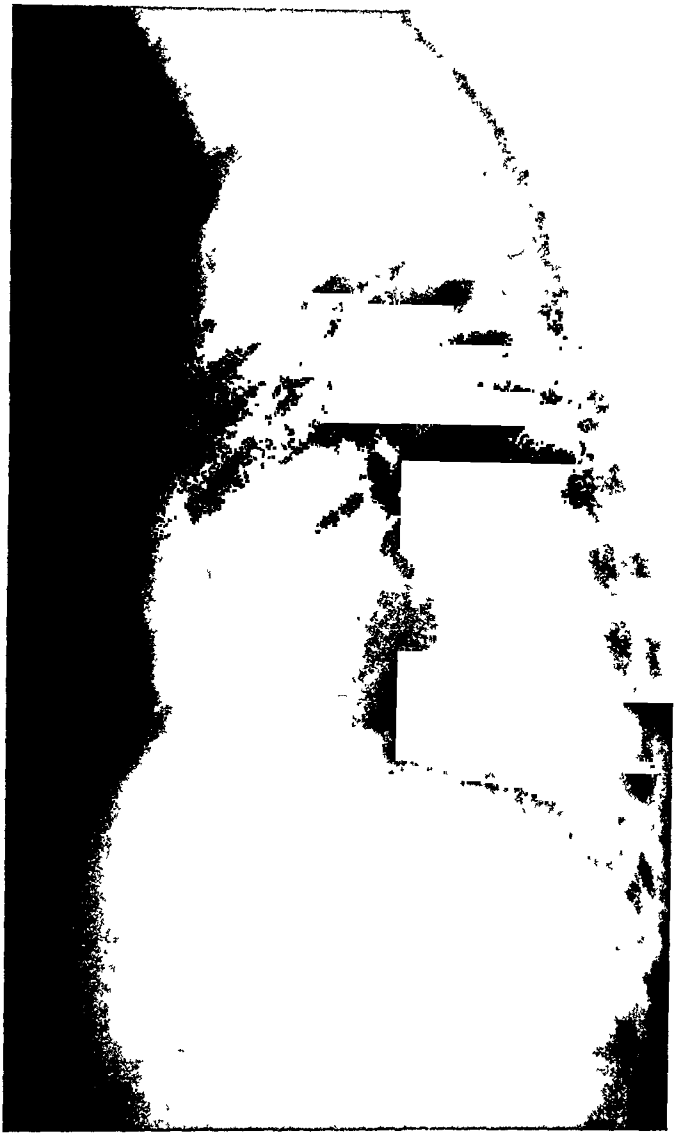

Fig. 5.—Lateral chest roentgenogram of a 2-year-old boy with a normal AP diameter and a measurement ratio of 0.4.

PREOPERATIVE STUDIES

Most of the early reports about this disease dealt with the technical aspects of structural correction. In the reports of Ravitch,[3] Dorner[4] Hansen[5] and others, not all of these individuals went on to enjoy a normal, unhandicapped life with a simple cosmetic deformity. The following routine and special studies were done with the purpose of adding more objective information in this limited age group.

In addition to the height weight percentile recording and the serial anteroposterior and lateral films of the chest mentioned above, the following additional studies are done before operative intervention is undertaken.

An electrocardiogram is obtained with multiple leads for its diagnostic value and as a base line study for the years ahead. Sixty-three patients had electrocardiograms that were interpreted as normal and 13 had changes associated with displacement of the heart reported as right axis deviation, inversion of T waves, and peaking of P waves. Two patients had bundle branch block.

In the children old enough to cooperate in a Master's type exercise tolerance test, we have entered this into the record, and have repeated this in the postoperative period.

Venous pressure and circulation time was determined in 10 individuals and they were all within the normal range.

Vital capacity and timed vital capacity has been obtained in all youngsters over 2 years of age. Although these are not highly accurate they give us some reassurance about normalcy in the younger group. This is done with an Emerson type spirometer and the figures are, with few exceptions, normal for their age and height in comparison with the standards established at the Harvard School of Public Health. They cooperate effectively in this simple study but cannot cooperate adequately for more detailed pulmonary function evaluation (see Special Studies).

We insist that these youngsters not be operated upon if there is any evidence of active upper respiratory tract infection or an abnormal coagulation mechanism.

A left anterior oblique photograph in deep inspiration and expiration is obtained pre- and postoperatively.

SPECIAL STUDIES

A. *Cardiac Catheterization.*—We feel that children with a diastolic murmur should be catheterized before operative intervention. The only patient with a diastolic murmur in this group had multiple congenital anomalies and was rejected as a candidate for operation. Five children, aged 2, 4, 6, 8, and 10, were catheterized preoperatively to determine if: (1) there was any demonstrable cardiac handicap in this age group, (2) if such a handicap was disclosed, how it related to the age of the patient and the severity of his deformity, and (3) would it be possible to improve abnormal preoperative cardiac catheter figures by operation.

Fabricius, Davidsen, and Hansen have reported on [illegible] tu [illegible] in funnel chest deformity in 26 patients as determined by [illegible] Five of these patients were 14 years of age or under an [illegible] corresponding to patients within the age limits of our study. Combining these studies: 9 of the children had normal pulmonary capillary, pulmonary artery, right ventricle and right atrial pressures with a normal cardiac output. One patient, a 14-year-old boy with only 1 cm. between the vertebral bodies and the posterior border of the sternum, had a slightly elevated right atrial pressure and a ventricular pressure curve similar to that seen in constrictive pericarditis (a diastolic plateau and dip). It is interesting that the pulmonary artery pressure was not elevated in any of the 10 children studied. It would seem that the neurocirculatory difficulties these youngsters have might be related to interference with cardiac filling. An impedance in the right outflow tract or an elevated pulmonary arterial pressure has not been demonstrated in this age group. It is quite possible that abnormal figures might be recorded in the spinomyelodysplasia group where funnel-chest deformity and structural scoliosis coexist. All patients showed a normal A-V difference, none were desaturated, and none showed evidence of auricular fibrillation in the monitoring electrocardiogram.. It can be said, in summary, then, that the occasional patient with abnormal cardiac catheter findings will be encountered at a much later date and probably in the third decade of life.

B. *Pulmonary Function Studies.*—Vital capacity and timed vital capacities can be determined in any youngster 2 years of age or over. Definitive pulmonary function studies require a good deal of cooperation and, up to the present time have not been made available in a well-standardized way for patients under the age of 5. Nine children have had detailed pulmonary function studies. Seven of these were completely normal or, if they had a measurable deficit, it was of minor degree in the range of 25 to 30 per cent below normal, quite obviously within the limit of error of a test that depends, to a large extent, on the motivation of the child.

Two patients with significantly abnormal figures were older and one could predict, from their general appearance and from their x-ray studies, that they had a reduced thoracic volume and that their figures would be well below the normal range on a height-weight basis. The deficits in these 2 individuals were great enough to make them unable to participate in vigorous activities, but they were completely comfortable at rest and with ordinary daily events (Table I).

The discouraging finding was that 1 patient had preoperative studies at the age of 8, was found to be 56 per cent of normal, and 2 years after operation was 54 per cent of normal. The second patient, studied preoperatively at age 11, was 65 per cent of normal, and at age 14, 3 years after operation, was 52 per cent of normal. There was no desaturation and there was normal gas transfer. The deficit appeared as one might expect in vital capacity, total lung capacity, and maximum breathing capacity. Table II summarizes the abnormal findings in these 2 patients compared with 2 younger patients in whom it was possible to carry out a satisfactory correction of the deformity. A report from the Oresundhospital, Copenhagen, by Hansen and Jacoby,[5] indicates that with

TABLE I PREOPERATIVE STUDY OF PULMONARY FUNCTION IN SEVERE FUNNEL CHEST DEFORMITY

R D —10 YR		% OF NORMAL
Maximum breathing capacity (L/min)	67	78
Vital capacity (c c)	1,720	64
Timed vital capacity		
1 sec % total	79	
2 sec % total	94	
3 sec % total	99	
Walking ventilation (L/M ^{2}/BSA)	15 8	
Total lung volume (c c)	2,300	65
Residual volume (c c)	640	
Residual volume/total capacity (%)	28	
Resting minute ventilation (c c)	8 955	
Resting minute O uptake (c c)	231	
Ventilation equivalent	3 9	
Pulmonary mixing index (% N_2)	1 68	
Breathing reserve	86 6	

severe deformity and a *severe* pulmonary function handicap, there may be significant improvement following operation They report 4 patients in whom differential bronchospirometry was carried out in the age range of 18 to 27 years The function in the two lungs was identical This is surprising in view of the fact that the heart is grossly displaced into the left hemithorax Combining the performance of the two lungs in order to compare them with the figures reported here, again there was no difficulty in the mechanics of respiration or in diffusion The deficit proved to be in vital capacity, total lung capacity and in maximum breathing capacity One of the patients is reported in detail His preoperative vital capacity both lungs combined, was only 430 c c , the total lung capacity was 850 c c , and the maximum breathing capacity 12 L Postoperatively this increased to *1,400 c c for vital capacity 1,900 c c total lung capacity* and 22 4 L maximum breathing capacity Fluoroscopically the change appeared to be principally in the elimination of paradox Here then we have an individual who, postoperatively, has only 25 per cent of normal lung function yet by comparison with the preoperative status, was vastly improved

TABLE II PULMONARY FUNCTION STUDIES IN PECTUS EXCAVATUM DEFORMITY*

PATIENT	AGE IN YEARS	TOTAL VOLUME CAPACITY (1 3)	VITAL CAPACITY (C C)	TOTAL LUNG CAPACITY (C C)	MAXIMUM BREATHING CAPACITY (L/MIN)
G R	3	N	600	---	
	6	N	1,150	1 837	35
N P	6	N	2 150	--	43
	8	N	3,120	3,680	74
H H	8	N	1,850 (56%)	----	--
	10	N	1,770 (54%)	----	61
R D	11	N	1,720 (64%)	2 300 (65%)	67
	14	N	2,100 (52%)	2 800 (56%)	84

*Significantly low pulmonary function figures (vital capacity total lung capacity and maximum breathing capacity) are not returned to normal by operation in the older child with irreversible deformity

In summary, then, in 7 of the patients studied, there was no evidence of pulmonary insufficiency In 2, the figures are suggestive of impending pulmonary insufficiency Complete and permanent structural correction of the individual over 8 years of age with severe funnel-chest deformity is only rarely accomplished. The center of the chest is raised but the declination of posterior rib segments remains and thoracic volume is not increased. If there is a pulmonary function deficit demonstrated preoperatively, there is little or no improvement in these figures postoperatively.

Looking ahead, one cannot predict with certainty the clinical course of any child with marked pectus excavatum deformity that remains uncorrected. Some, to be sure, will develop paroxysmal fibrillation, precordial or radiating pain, syncope, low blood pressure, dyspnea at rest or on exertion, cardiac failure and/or pulmonary suppuration.

MULTIPLE CONGENITAL ANOMALIES

Six patients had multiple congenital anomalies. Having had the bitter experience of losing one of these patients and finding reports of others,[7] multiple anomalies might be suggested as a categorical contraindication to operative correction of pectus excavatum deformity. In 1 case there was coexisting Marfan's syndrome with a dissecting aneurysm of the thoracic aorta. This burst in the immediate postoperative period. In our patient, a 16-month-old child, there was an associated cleft palate deformity which had been successfully corrected, scoliosis, pectus excavatum deformity (severe), and poor central nervous system development. Another patient, 2 years of age, with Marfan's disease and congenital absence of the pectoral muscles on the right, was rejected for operation. The third patient was a 2-year-old with Klippel-Feil syndrome, ovarian agenesis, severe pectus excavatum deformity, and an element of mental retardation. The fourth had multiple hemivertebrae, absence of costal cartilages, D_3 to D_8, a deficiency of intercostal muscles, a diastolic and systolic murmur, and severe pectus excavatum deformity. She was rejected for operation because of the complex murmur and the multiple associated anomalies. The fifth, 7 years of age, had bilateral microtia, mental deficiency, and a roaring Roger-type murmur. The sixth and oldest patient, 10 years of age, had scoliosis, deficiency of abdominal muscles, bronchiectasis, and pectus excavatum deformity. This probably again represents spinomyelodysplasia. His bronchiectasis is arrested and he has been free of pulmonary infection for some time.

Continuing to operate upon this group will result in excessive postoperative morbidity and/or mortality. It will add unnecessary deaths in connection with the surgical management of pectus excavatum deformity and will discredit the procedure.

OPERATIVE MANAGEMENT

It is seen in Table III that the first thirty-four operations were performed after the method of Sweet.[8] Parallel chondrotomies are carried out in two rows with anterior cortex sternotomy, elevation of the sternum, and reconstruction of the chest wall, using the elevated sternum as the keystone of an arch. The cut cartilage ends are accurately resutured. This seemed appealing because, upon completing reconstruction of the chest wall, there was a stable situation These patients seemed to have little flail motion when they were allowed to resume their own breathing cycle. In 4 patients we extended this operation to include the costal complex and there was less effective breathing postoperatively. The costal arch plays a very important role in diaphragmatic excursion.

TABLE III. TYPE OF OPERATION PERFORMED

1. Multiple chondrotomies with suture fixation (Sweet)	34
2. Subperichondrial resection with transverse sternotomy (Garnier, Lester, Ravitch)	39
3. Xiphoidectomy and retrosternal freeing (Brown, Lester)	2
4. Cartilage resection with rib strut (Dailey)	1
Total	76

There was a great deal of blood loss with this procedure We were not able to stay out of both pleural cavities in any case so that we had, by definition, the postoperative problems of bilateral thoracotomy. These youngsters had occasional atelectasis, they had to be carefully checked for tension difficulties, and many developed pleural cavity collections of blood and/or serum that required tapping. We were fortunate not to have mediastinal or pleural cavity infection in this group. As we gradually arrived at the time of election for operation we found that a better immediate and permanent correction and a less hazardous one could be obtained using elements of the operations described by Garnier, *Lester,[10] and Ravitch.[11]*

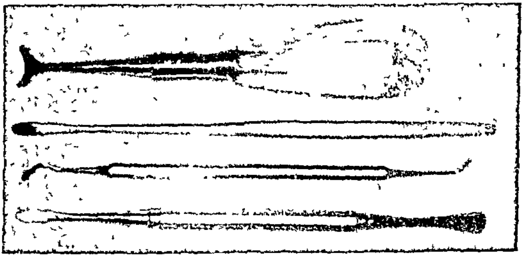

FIG. 6.—Dental instruments are ideally suited for performing costal cartilage resections in the younger age group

Our operative procedure can be described briefly. We use a short, transverse skin incision over the maximal point of the deformity. It is not necessary to carry this beyond the nipple line. Subcutaneous tissue dissection is avoided. The pectoral muscles are swept off the chest wall and the bony thorax is exposed from the angle of Lewis to the costochondral junction on each side from the third to the eighth ribs. The xiphoid is grasped with an Allis clamp and is carefully cut through at the gladiolar junction. A technical innovation that we *have arrived at is to make* T-shaped incisions with the short [illegible] of th[illegible] at the sternal border of the costal cartilage, extending the [illegible] costochondral junction. The cartilage envelope is opened [illegible] instruments (Fig. 6). We have found that the usual ri[illegible] are inadequate for this maneuver, and the younger the patient, the more this is true. It is possible, and has been possible in the last 24 patients, to carry out symmetrical cartilage resections on each side without entering either pleural cavity and without injuring the internal mammary vessels. It is possible to clear the cartilage medially for about three quarters of its circumference, permitting it to be grasped with an Allis clamp. Then, as upward pressure is exerted, using a fine blade, the cartilage is divided at its sternal insertion. The cartilage end lifts up. It is then possible to encircle the costal cartilage and gain access to a dry, blue-gray periosteal envelope and to quickly shell out these cartilages, breaking them off at the costochondral junction (Fig. 7). We have gone beyond the costochondral junction in a few cases where it did not seem to include the lateral extent of the deformity. The recti are not swept off the costal arch. The intercostal bundles are not divided. An anterior cortex sternotomy is performed, creating a broad V-shaped trough. The sternum can then be drawn forward, fracturing the posterior cortex. It is held in this new position using 1-0 silk, and the periosteum is reinforced with 4-0 silk. The muscles are reapplied to the chest wall with 3-0 silk. We are careful

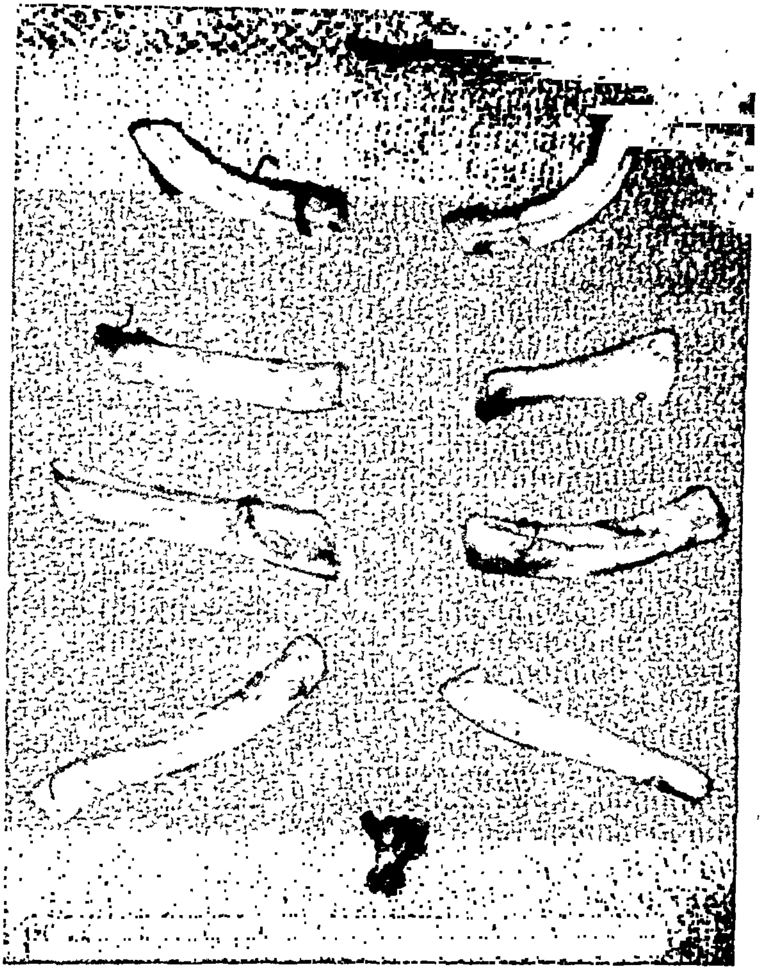

Fig. 7.—Resected costal cartilage segments, xiphoid, and a wedge of gladiolar cortex.

to obliterate dead space by suturing the pectorals to the intercostal muscle groups and to the periosteum of the sternum. One other technical point is that we then run off the inverted Y shaped silk closure of the pectorals and the rectus muscle with 3-0 chromic catgut, making this a water-tight situation and separating it from the superficial layers of the wound. There follows a subcuticular build-up using fine catgut with interrupted 5-0 silk to the skin.

We do not carry out an extensive mediastinal dissection with the finger. We have passed a finger behind the sternum, in the midline in each case, to be sure that there are no remaining restricting elements. However, in none of these patients have we encountered anything but loose areolar tissue.

An elastoplast dressing is applied with no protective support and no type of external traction is used.

Gravimetric estimates of blood loss has been as low as 155 c.c. and averages about 350 c.c. in this 2- to 5-year age group. Operative time has been in the range of 1½ to 2 hours. This seems important because of the great responsibility that the anesthetist has in this operation and fatigue is a function of time in monitoring this complex respiratory situation. It also decreases the amount of whole blood replacement necessary and adds substantially to the smoothness of the postoperative course.

ANESTHETIC MANAGEMENT

Anesthetic management is by far the most difficult and most responsible aspect of the operation in this age group. It is, at best, a tricky anesthesia and at its worst, a downright dangerous one. The two deaths that we report have both been in connection with anesthetic management. In one the problem was a complex one because of multiple congenital anomalies. In the other, a 4-year-old boy, there was a clear-cut cardiac arrest on the basis of airway anoxia that occurred as the skin sutures were being placed after a 1½ hour extrapleural procedure with minimal blood loss.

One problem in this closed, temporarily flail chest is in keeping the medium pressure in the anesthetic system in an atmospheric range. It does not seem possible to accomplish this accurately with the automatic breathing devices that have recently come on the market. If this can be kept a short procedure and if fatigue is not to enter in, it would still seem best to manage these patients with controlled respiration and manual control of the bag. It may be necessary, in order to keep the lungs inflated, to have occasional pressures as high as 100 cm. of water. If continued, this may so interfere with cardiac filling that you precipitate a cycle of difficulties in this respect. We have asked the anesthetist to place a stethoscope at each base and to watch vital signs and blood replacement with extreme care. It is largely a matter of experience with the manual control of breathing and a sense of adequate ventilation at the alveolar level. One of the problems here is that the anesthetist cannot see the lung—that he has a closed and not an open chest. On the one hand, there is failure to accomplish adequate ventilation at the alveolar level and, on the other, the danger of interfering with cardiac filling by overdistention of the lungs. The postoperative sequelae of vigorous overdistention of the lungs for any period is well known and has been encountered twice. This sets the stage for ineffective ventilation, atelectasis, and cardiac failure.

Some of these youngsters have developed twitching, some have had unexplained periods of desaturation, others have had hyperthermia during the course of anesthesia.[12]

It must be stressed that anesthetic management is the most dangerous aspect of the surgical correction of this disease and that one must be very detailed in the preoperative evaluation of these patients.

COMPLICATIONS

The most frequent postoperative complication (Table IV) was recurrence of the deformity. This occurred in 7 patients, if one considers the continued progression of the deformity after xiphoidectomy alone carried out in 2 patients in the first year of life. The five true postoperative recurrences occurred in the first part of the series using the Sweet technique. Four of them occurred in youngsters over 6 years of age. Two of these were severe enough to justify correction. One was done by subperichondrial resection with external traction for a period of 2 weeks. The other has not been operated upon.

TABLE IV. POSTOPERATIVE COMPLICATIONS

Recurrence of deformity	5
Keloid formation	4
Marginal necrosis of skin flap	4
Superficial wound infection	3
Chondritis	2
Cardiac arrest	1
Cardiac failure	1

The thing that has confused us about recurrence of the deformity is that it does not develop early and does not relate to whether one does or does not use external skeletal traction. None of the reported internal fixation or external traction methods are continued for more than a month, and most of them are discontinued at the end of the period of hospitalization—roughly 10 days to 2 weeks. The patients with recurrence all look satisfactory at the end of the first month and then, much to one's surprise, after 6 months or a year or 2 years, these youngsters come back with a reacquired funnel. In spite of this, their over-all improvement is satisfactory, they have lost their paradox, and they go on to acquire adequate AP diameter unless they had a markedly decreased AP diameter at the time of operation. The rib strut operation suggested by Dailey,[13] has been tried in only 1 patient. This would seem to be a worth-while maneuver in the older child with recurrence. We have had no experience with the Kirschner wire support of these deformities.[11]

Keloid formation related directly to the use of the vertical incision; this was used eighteen times. Marginal necrosis of the skin flap occurred either with the long vertical incision or in the few patients that we attempted an inverted

"U" incision. The apex of these flaps sloughed without exception. We then shifted to a transverse incision with a slight convexity upward, extending out to the nipple lines and encountered no more keloids or marginal sloughs. Superficial wound infection occurred in 3. Chondritis occurred in 2—1 of these had to be reoperated upon for removal of multiple parasternal silk sutures. The two deaths in this series, listed here as cardiac failure and cardiac arrest, are reported above.

The great majority of patients operated upon at the ideal age, using an extrapleural procedure, have a completely uneventful postoperative course, are allowed to be up and around after the first day, and are discharged home without a dressing on the seventh day (Fig. 8).

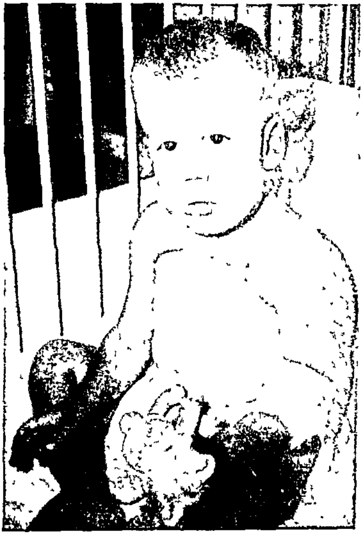

Fig. 8.—A 28-month-old boy on his first postoperative day Cardiac catheterization and pulmonary function figures were normal

FOLLOW-UP

The follow-up period extends over a 7-year period from 1951 to 1958. In 1954 and 1955, we were operating upon nearly every youngster that presented a moderate to severe deformity. With disappointments in the older group, with recognition of the risk in the multiple congenital anomaly patient, with a better understanding of operative and anesthetic management, and with better experience in predicting spontaneous improvement, we have arrived at the policy of management described above. We do not now operate upon any youngster under 2 years of age. If one accepts thi [illegible] on [illegible] ore than half of the patients will drift through to normalcy [illegible] enti

Eight patients have been followed less than 1 year; 10 patients, 1 year; 17, 2 years; 10, 3 years; 15, 4 years; 9, 5 years; and 7 patients have been followed 6 years or more.

Three of seven recurrences have been corrected surgically. Three are of a minor degree and one is a complete failure but secondary operation has been refused.

The results in 67 patients are considered to be excellent.

SUMMARY

1. We are satisfied with the long-term cosmetic and functional result following an extrapleural, subperichondrial resection operation, without external support, performed on selected individuals in the 2- to 5-year age group with pectus excavatum deformity.

2. Two of 76 patients died in an attempt to correct this deformity. Seven patients developed some degree of recurrence and therefore were considered to be unsatisfactory even though subsequently corrected by a second operation. An excellent result was achieved in 67 patients.

3. Studies of cardiopulmonary function are reported. These indicate that within the ideal elective period for operation, 2 to 5 years, there is no objective evidence of abnormal function. There is no evidence of pulmonary insufficiency until the volume of the thorax is grossly reduced below normal in the first decade of life. Two individuals had reduction in pulmonary function to the 50 per cent level. They were not returned to normal levels by elevation of the sternum. Surgical correction at a later age, although cosmetically partially effective, does not convert the habitus of these individuals to normal. When there is objective evidence of a cardiopulmonary handicap, they may be improved from severe to better but are not returned to a normal range.

4. Because of the inability to predict the future course of children with marked, progressive pectus excavatum deformity, they should be recommended for operation by the third year of life if they are to be restored to normalcy in all cases.

The pulmonary function and cardiac catheterization studies were performed by the Cardiopulmonary Laboratories of the Harvard School of Public Health, the Children's Medical Center (Sharon Cardiovascular Unit), the Boston Floating Hospital, and the Boston City Hospital.

A number of these patients were operated upon at the United States Naval Hospital, Chelsea, Mass., under the direction of Captain Louis Haynes. *I am indebted to him for* the able assistance and encouragement given during the early part of this study.

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(For Discussion, see page 724)

PECTUS EXCAVATUM: AN APPRAISAL OF SURGICAL TREATMENT

Paul C. Adkins, M.D. (by invitation), and Owen Gwathmey, M.D.,
Washington, D. C.

It is now well established that surgical correction of a funnel chest deformity is feasible and relatively safe. There is, however, little agreement in the literature concerning age limitations, if any, for surgical correction, and even less unanimity of opinion about the actual surgical technique to be used. The purpose of this presentation is to review our experiences in the correction of pectus excavatum deformities over the past 5 years. Our present approach to this problem is one which has been achieved by a process of trial and error. The operation is best performed during childhood and correction of these deformities is usually less formidable at this time than in later years. ~~However, our ex-~~periences have led us to believe that with our present techniques, correction of a pectus excavatum may be carried out on teenagers and young adults with equally good results.

~~We have little~~ to add in the realm of speculation concerning etiology of this deformity. Claim has been made that a hypertrophied or contracted substernal ligament may be the etiological agent.[3, 11, 14, 17] Although some attachment of the undersurface of the sternum to the diaphragm may be readily apparent when this deformity is seen in infancy,[12, 13] we are not sure that we have ever encountered a hypertrophied substernal ligament in our surgical experience. Once past infancy, however, there appears to be considerable variation in the amount of progression of this deformity. Following children over periods of several years we have found some sternal depressions to become more pronounced, others remain static, while others may ~~become even less~~ apparent. Thus far we have been completely incapable of predicting the natural progression of any of these deformities.

INDICATIONS FOR OPERATION

The prevention or correction of ~~cardiorespiratory embarrassment~~ is considered a prime indication for operative correction of a pectus excavatum. There can be little question that reduction in the anterior-posterior diameter of the mediastinum, resulting from sternal depression, can cause ~~distortion or~~ rotation of ~~the heart and~~ great vessels.[2, 7, 16, 20] The cough mechanism is often

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From the Department of Surgery, The George Washington University, Washington, D.C.
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impaired as a result of this deformity[4] Although, cardiorespiratory problems are relatively unusual during childhood,[9, 20] progression of the deformity may result in later difficulty[16] The other and equally valid indication for surgical correction is for cosmetic and psychologic reasons A depression or deformity of the chest wall may be a sou [illegible] during adolescence and young a [illegible] on of such a deformity is well justified even in the absence of symptoms

SYMPTOMS

It is our impression that the *symptoms associated with a pectus excavatum* are probably more frequent than is generally appreciated[16] Although patients or the parents of the patients with a pectus excavatum frequently disclaim any limitation of activity, closer questioning often reveals that such patients have been slightly below normal in their activities when compared with their contemporaries *Many such patients have had rather frequent and prolonged respiratory infections* Six of the children whom we have seen have been treated by their pediatrician for varying periods of time for so called "allergic bronchitis" The five adults in this series have all had some degree of disability associated with their deformity In each instance the disability consisted of *moderate to severe exertional dyspnea and fatigability*

CLINICAL MATERIAL

Thirty nine patients with a pectus excavatum have been seen at The George Washington University Hospital in the 5 year period ending in October 1957 Five patients were considered to have a minimal deformity with no associated symptoms and no operation was advised Six small children were believed to be candidates for operation, but surgical intervention has been deferred until they are older One adult patient with a rather marked deformity and associated symptoms refused operation The remaining 27 patients have been subjected to a total of twenty nine operations for the correction of a pectus excavatum deformity There were, in the entire group of patients seen, 24 males and 15 females In the patients who underwent operation the age range was from 3 months to 34 years (Table I) Four of these patients were adults Two of the adults showed associated manifestations of Marfan's syndrome

TABLE I PECTUS EXCAVATUM
AGE DISTRIBUTION AT TIME OF OPERATION

AGE	NO OF PATIENTS
3 mo 18 mo	5
18 mo 3 yr	4
3 yr 6 yr	6
6 yr 16 yr	8
Over 16 yr	4
Total	27

SELECTION OF OPERATION

There is little doubt that the simple operation described by Brown[3, 4] (excision of the xiphoid and division of the substernal ligament) out with a high degree of success if performed prior to the age of 1 year (Fig. 1). The operation is brief, relatively atraumatic, and a satisfactory cosmetic result may be anticipated, particularly if there is some degree of paradoxical motion of the depressed portion of the sternum. In our hands in 5 cases, the operation has yielded a good to excellent cosmetic result in four instances (see Table III). In the fifth case, an 18-month-old female, the initial operation produced virtually no cosmetic improvement, consequently, a subsequent, more radical operation with resection of the costal cartilages was performed at the age of 3½ years. Thus, even though the maximum cosmetic result may not be achieved from this simple operation of Brown, it may make a second operation at a later date less formidable.

Fig 1.—Photograph of a 2-year-old child, 18 months after simple division of substernal ligament. No residual sternal depression

It is presently our policy to defer operation, if at all possible, on patients between the ages of 1 and 3 years. During this age, the expected response to the simple operation of Brown is not satisfactory.[9] At the same time, these children are not considered ideal candidates for the more radical operation of chest wall reconstruction. Although they can tolerate the surgical procedure itself fairly well, they are unable to cooperate in the immediate postoperative period. They do not cough, and a tracheostomy may be necessary. The one death in this series was in a child of 2½ years of age who developed an acute bilateral pneumonia 24 hours after operation. She had a history of frequent severe respiratory infections and allergic bronchitis. She was considerably undeveloped for her age. The child was operated on at this age, with some misgivings, in the hope that the correction of a severe pectus excavatum deformity might alleviate some of her respiratory problems and increase her growth. Although the operation was uneventful, this child developed respiratory difficulty approximately 12 hours postoperatively and pursued a rapid downhill course. The 3 other children operated on in this age group have also been more difficult to manage postoperatively than the older children. We now prefer to wait until these children have reached a minimum age of 3 years, both mentally and physically.

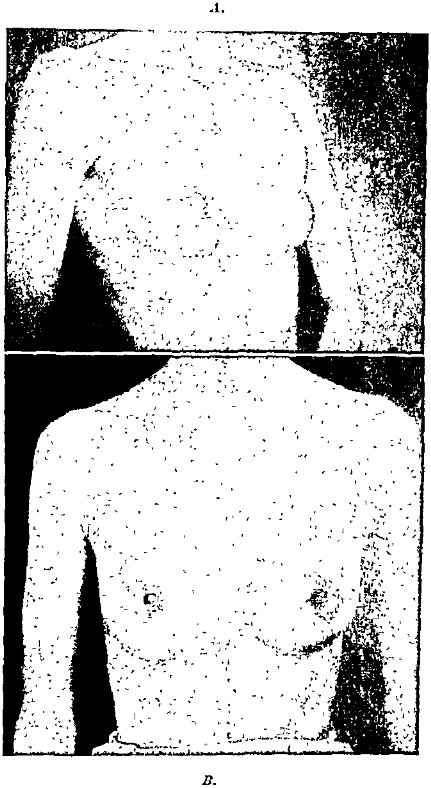


Fig. 2.—*A*, Preoperative photograph of a 29-year-old women with marked pectus excavatum. This patient had moderate exertional dyspnea.
B, Postoperative photograph demonstrating submammary scar with downward extension.

In patients over the age of 3 years, some form of plastic reconstruction of the anterior chest wall has been employed. The principles of such an operation are:

1. Adequate exposure of the depressed portion of the sternum and adjacent deformed costal cartilages.

2. Freeing of the undersurface of the sternum from its ligamentous and fascial attachments to the mediastinum and diaphragm.

3. Resection of the involved costal cartilages, including division of the attachments of the rectus muscles to the costal margins when deemed advisable.

4. Osteotomy of the sternum. This may be either a transverse osteotomy or "T" fracture depending upon the severity of the deformity and the ease of adequate mobilization of the sternum (Fig. 3).

All operations have been performed under general endotracheal anesthesia. We currently favor the bilateral submammary incision for several reasons. It yields a far better cosmetic result, especially in females, while affording excellent exposure of the lower sternum and adjacent costal cartilages. In addition, it gives easy access to the costal margins, which often flare and need tailoring. This type of transverse incision does not overlie the osteotomy of the sternum, hence a direct bone marrow to skin communication is avoided.

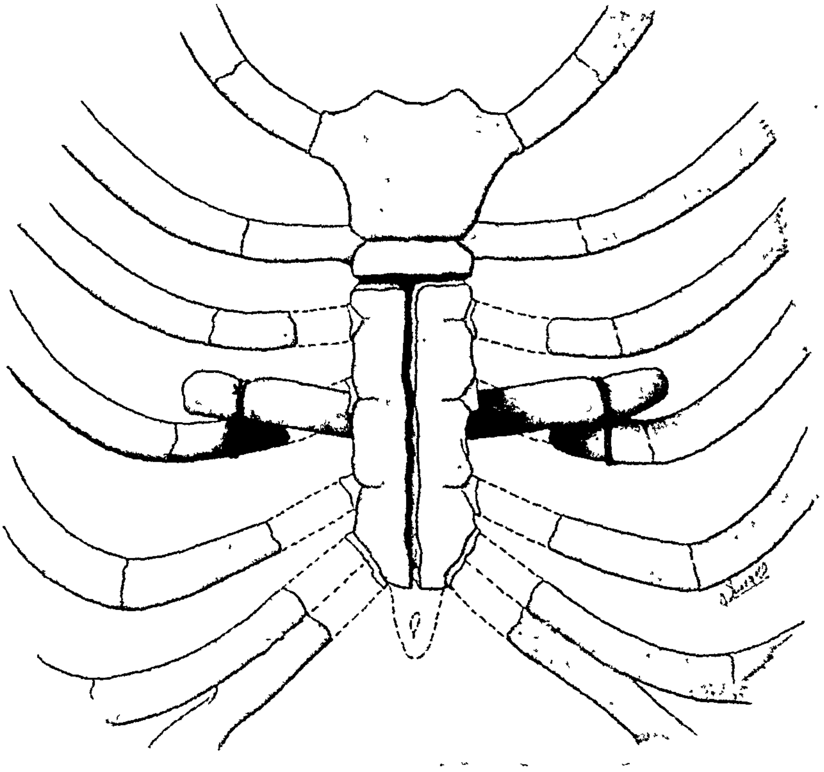
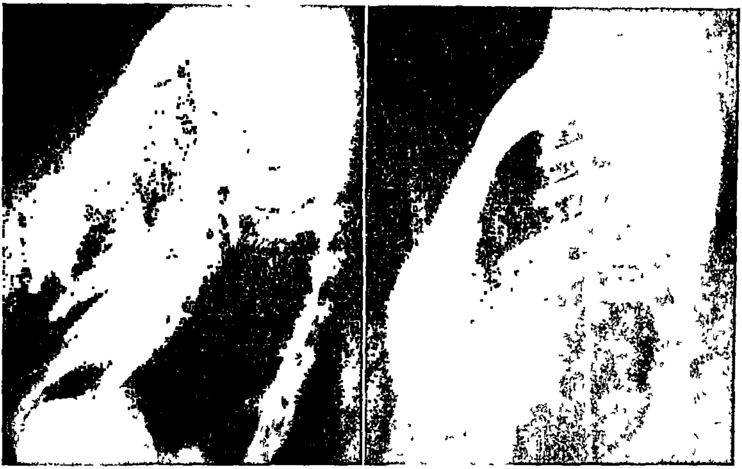


Fig. 3.—Diagram showing homologous rib graft anchored in place and one type of osteotomy of the sternum. The rib strut is also anchored to the pectoral muscles (not shown).

We do not reflect the pectoralis muscles off the rib cage. These muscles can be split in the direction of their fibers to expose each cartilage to be resected. The muscles can be then reapproximated with a few interrupted sutures. We believe that this avoids a considerable amount of dissection, unnecessary trauma, and blood loss. It does not interfere with the over-all cosmetic result.

A variety of techniques have been described for maintaining the sternum in an elevated position once it has been fully mobilized.[1, 2, 5, 6, 8, 9, 10, 13, 17, 18, 19, 21] We have tried a number of these techniques, including forms of external traction, resuturing the costal cartilages and sternum together after wedge osteotomy,



A. *B*

Fig. 4.—*A*, Preoperative roentgenogram of same patient as Fig. 2, A.
B, Postoperative roentgenogram after chest wall reconstruction using homologous rib as a strut.

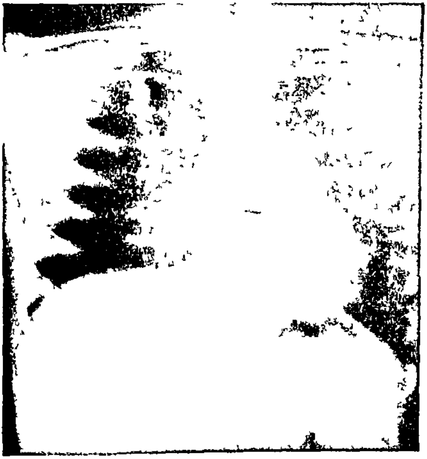


Fig. 5.—Postoperative roentgenogram showing use of homologous rib strut in a 3-year-old child. Good cosmetic result.

and the use of a homologous rib graft as a strut. The technique of passing a homologous rib graft beneath the sternum and anchoring it to the appropriate costal cartilages was first advocated by Dailey in 1950.[5, 6] We started using this technique on adults and teenagers with severe sternal depression. It was found to be so satisfactory that the use of such a strut has now been extended to the younger age group. A strut has been used on 4 children under 6 years of age in our series.

We believe this technique has several advantages over other methods. No form of external traction device is necessary, obviating the need for cumbersome appliances on the chest wall. The strut gives stability to the sternum and anterior chest wall, preventing paradoxical motion in the postoperative period. The sternum is readily held in a slightly overcorrected position, a situation which we believe gives a better cosmetic result in long-term follow-ups, particularly in those children who are in a period of rapid growth. It has been our experience to perform operations without the use of a strut, and with an apparently good cosmetic result at the conclusion of the operation. We were then disappointed and chagrined to see these patients a year or 18 months later with some degree of recurrence of their sternal depression. This has not happened in any case in which a strut has been used; some patients having been followed 5 years or more.

Fig. 6.—Homologous rib strut postoperatively in a 23-year-old patient. Note notch cut in strut

A strut has been utilized in the correction of a pectus excavatum in 14 patients. For the most part we have used a homologous rib graft as the strut.

These ribs are removed from patients undergoing thoracotomy, who are free from infectious or malignant diseases. The ribs are then cleaned thoroughly and preserved in a deep freeze in sterile containers. In three instances we have used synthetic struts made of a methylmethacrylate resin. These were fashioned at the time of operation, but proved to be rather cumbersome and were accompanied by an excessive amount of tissue reaction in the immediate postoperative period.

The major disadvantage to the use of a strut is the possibility of infection. This has occurred in 4 cases as a persistent draining sinus postoperatively. In each case, the strut was removed easily, 1 to 4 months after the initial operation. In only one instance was there any loss of cosmetic result. This was in a 19 year old male with Marfan's syndrome. After the removal of the strut in this case, the sternal depression was again present, but to a much lesser degree than preoperatively. Those patients in whom a strut was used but not removed, showed gradual absorption of the homologous bone over a period of 6 to 8 months.

The other disadvantage to the use of a homologous rib graft has been the inability to obtain enough variation in size and curvature of the graft to meet the needs of the individual patient. To avoid this and to attempt to circumvent the problem of infection, we are currently working on the use of a thin, flat, stainless steel bar. This bar has several notches on either side to facilitate anchoring to the costal cartilages, and a hole at either end to make removal easy. It is proposed to use these bars as struts, and remove them electively after complete healing of the chest wall has occurred.

POSTOPERATIVE MANAGEMENT

The occurrence of a unilateral or bilateral pneumothorax during these operations has not been a problem. This has occurred ten times in twenty nine operations, including five instances in children under the age of 6 years. In 4 cases the pleura was inadvertently entered bilaterally. If penetration into the pleural cavity is recognized at the time of operation, an intercostal catheter for water seal drainage is inserted at the conclusion of the procedure. In any event, a portable chest roentgenogram is taken in the operating room at the conclusion of each operation. If a previously unrecognized pneumothorax is seen at this time, it is a simple matter to insert an intercostal catheter since the patient is invariably still asleep. No untoward effects have resulted from the creation of a pneumothorax. Chest catheters can almost always be removed within 24 hours, as soon as there is radiologic evidence of full re-expansion of the lung.

The major problem in the immediate postoperative period has [illegible] keep a clear tracheobronchial tree. This is particularly true in the [illegible] children during the first 48 hours after operation. The patient [illegible] allowed out of bed by the fourth or fifth postoperative [illegible] hospital by the eighth or ninth day.

There is another important aspect of the postoperative care which we do not believe has received sufficient attention in the literature. This is the problem of postural training and over-all muscular balance. It has been our experience to perform what was apparently a successful correction of a funnel chest deformity, only to find that the patient was still potbellied, stoop-shouldered, and kyphotic. Any significant degree of sternal depression, which has been present for a period of years, is accompanied by a weakness and shortening of the pectoral, trapezius, and abdominal muscles and, to some degree, the other accessory muscles of respiration. Stretching and strengthening of these involved muscles, as well as postural training, plays an important role in the achievement of a successful cosmetic result. Exercises to improve the strength of these muscles and to regain their normal length can be taught to children as young as 4 years of age, and can be supervised by parents at home. These exercises and postural instructions are usually started at the end of the first postoperative week by members of our Department of Physical Medicine. In those children too young, or unable to follow such a program, the course is started as soon as they have reached a suitable age. The continued use of such exercises and training has improved the over-all appearance of the patients. We feel that this is an important adjunct to operation and contributes to a lasting good cosmetic result.

RESULTS OF OPERATION

Objective evaluation of results after operations for pectus excavatum is admittedly somewhat nebulous. Our evaluation of improvement is based on cosmetic appearance 6 months or more after operation. On this basis we have classified results as follows: (1) good, meaning no significant residual sternal depression; (2) fair, some residual depression but improvement over the preoperative status; (3) poor, showing no significant change over preoperative appearance. On this basis, the over-all results after all operations are given in Table II. Thus, twenty-one results could be classified as good, and four as fair. These results include 2 cases in which secondary operations were necessary to improve the cosmetic appearance.

TABLE II. PECTUS EXCAVATUM
RESULTS—ALL OPERATIONS

AGE	GOOD	FAIR	POOR	DEAD
3 mo.-18 mo.	4	-	1*	-
18 mo.-3 yr.	2	1	-	1
3 yr.-6 yr.	4	1	1*	-
6 yr.-16 yr.	6	1	1	-
Over 16 yr.	3	1	-	-
Total	19	4	3	1
Final total	(21)		(1)	

*Reoperation with good results.

In 14 patients in whom a homologous rib graft or other strut was used, 12 could be classified as good results (Table III). There was one fair result, and this was in a patient who had the strut removed approximately 1 month postoperatively. One death occurred in this group, as mentioned previously.

In the group in which no strut was used the over all results were not as gratifying In the 5 infants subjected to the simple operation of division of the substernal ligament, 4 had good results, and 1 infant required a second operation In 10 patients who had chest wall reconstruction without employing a rib graft as a strut the results in 5 cases were fair or poor Good results were obtained in the remaining 5 cases, including 2 in which an external traction device was used One of the patients in this group with a poor result has been subjected to a second operation using a homologous rib graft with a good result One other patient needs a secondary operation, but this has not yet been done

TABLE III PECTUS EXCAVATUM
RESULTS OF VARIOUS OPERATIONS

	GOOD	FAIR	POOR	DEAD
Division of ligament	4		1	
Reconstruction—no strut	5	3	2	
Reconstruction with strut	12	1		1
Total	21	4	3 (1)	1

In terms of subjective symptoms, the 4 adults in this group had all definite symptoms of exertional dyspnea and fatigability prior to operation In each instance, after correction of the depressed sternum there has been moderate to marked improvement in their symptoms In addition, all of these patients have a high morale as the result of their cosmetic improvement

CONCLUSIONS

1 Surgical correction of a pectus excavatum is feasible in teenagers and young adults, as well as during childhood

2 Excision of the xiphoid and division of the substernal ligament gives satisfactory results if the operation is performed prior to the age of 1 year

3 The best cosmetic results in our hands, in both children and adults, have been achieved by the use of a strut passed beneath the sternum

4 The use of muscular exercises and postural training is an important adjunct to surgery in achieving a good over all cosmetic result

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DISCUSSION

(PAPERS BY WELCH [PAGE 697] AND ADKINS AND GWATHMEY [PAGE 714])

DR. CHARLES W. LESTER, New York, N. Y.—If I seem to dwell on my points of disagreement with these papers it does not mean that I do not consider them excellent. The condition of funnel chest is so complex that conclusions cannot be reached from a limited group of cases, especially in a group of cases all before the age of puberty. Many funnel chests do not appear until the approach of adolescence and may not give symptoms before the age of 15. Yet operation on these patients produces such marked increase in exercise tolerance that they all recognize the improvement, functional studies to the contrary notwithstanding.

I believe that disproportionate overgrowth of the ribs is a factor in the late appearance of funnel chest, just as I believe that it is the most important factor in the protrusion deformities. Heredity is also a factor in both types of deformity and it is obvious that our concept of the etiology of anterior chest-wall deformities should be revised. That the pull of the diaphragm during inspiration is a dominant mechanism in producing funnel chest is obvious.

This diaphragmatic abnormality interferes with effective cough so that a minor respiratory infection can become major and pneumonitis or chronic bronchitis can result. If this occurs in infancy, operation should be undertaken regardless of the age and, in babies under one year of age, the simple sternoplasty should be used because it *is* simple. A radical sternoplasty may be necessary a couple of years later but, in the meanwhile, the baby has recovered from the infection and has had a chance to develop in a normal manner; and at least half of my patients who had simple sternoplasties have not required a radical sternoplasty later.

Furthermore, because the chronic pulmonary infection can produce a postoperative cough after radical sternoplasty which, with an unsupported sternum, can ruin a good result, I shall continue to pass wires under the sternum, carry them out onto the chest wall and fasten them into a ''ladder'' (Brown's terminology). This is for support and not traction. The support is easily applied, easily removed in a week or less and the procedure is less time-consuming than operations devised to avoid it. The danger of infection is highly overrated. I have never had an infection when wires were used and only once with a rib strut, and this did not compromise the result.

DR. J. KARL POPPE, Portland, Ore.—I rise to report the case of a 32-year-old woman with anginal pain on effort in whom the repair of a funnel chest deformity markedly decreased her symptoms and permitted her to recover from narcotic addiction. This operation was performed during the late 1940's before the substernal rib strut was being used. About 3 years later, the funnel chest deformity recurred, associated with recurrence of severe anginoid symptoms. These symptoms could be exaggerated by pressure over the depressed sternum.

This case serves to illustrate my contention that the surgical repair of a funnel chest deformity can produce improvement in cardiorespiratory disability in the adult.

DR. RALPH A. DORNER, Des Moines, Iowa.—I rise merely to put in a word for the use of a preserved rib as a strut rather than using a rib from the patient at the time of surgery. In a series of about 20 cases, I have used preserved ribs and feel that this can cut down on the operative time and operative trauma. Furthermore, the flat portion of an adult rib can be inserted beneath the sternum with considerably less difficulty than is encountered in using the young patient's rib with its much greater curvature. With the use of a rib strut, one can elevate the sternum and know that it will remain in place with an ultimate good result. The only complication in my series has been in one patient in whom I put the rib while it was still very cold. This patient developed a pleural effusion which was found to be sterile on aspiration and did not recur. I do not know whether the coldness had anything to do with the effusion or not, but I have been allowing the rib to warm as it is soaked in Terramycin solution prior to surgery.

I feel that with the use of a rib strut one can elevate the sternum and know that the condition will remain corrected. It is now 9 years since my first "strut" patient was operated upon.

DR. PAUL W. SANGER, Charlotte, N. C.—The pathophysiology in patients with deformed chests is hypoventilation, as it is with any type of thoracic cage deformity with a fixed chest wall, whether it be kyphosis, pectus excavatum (funnel chest), or pectus carinatum (pigeon breast). These individuals have lost the bellows effect of the chest which is absolutely necessary to bring a sufficient quantity of air for exposure to the gaseous exchanging surface of the lung. I think in the pectus excavatum and carinatum the deformity is created by overgrowth of the costal cartilages. The patients selected for operation are those with symptoms of breathlessness, palpitation, or with objective signs of paradoxical breathing, irrespective of age.

(slide) I do not think you should refuse to operate on a child just because he is young if he is having respiratory difficulty. Twenty-six of our patients have been under the age of 3 years.

(slide) Of the 103 patients we have operated upon without a single death, all were put through the gamut of physiologic studies, and we have found that a low pH was a consistent abnormality. Also, the pulmonary arterial pressure, even although it may be normal at rest, remains high for an abnormally long time following bicycle exercise of the legs.

I believe the cartilages should be removed entirely and only a small strip of the perichondrium, after it has been shortened, is attached to the undersurface of the sternum. I do not use any form of external fixation, nor do I object to entering the pleural cavity; as a matter of fact, I frequently drain the pleural cavity in order to avoid repeated pleural aspirations which are otherwise necessary.

This series represents patients we have operated upon in the last 13 years. Many of them have since married and some have even had service in the Marine Corps.

DR. MARK M. RAVITCH, Baltimore, Md.—I rise to emphasize what previous discussers have already stated, that this is a condition which causes symptoms, and that patients should be operated upon for relief of symptoms and prevention of the development of symptoms, as well as for correction of the cosmetic and postural deformity. We have seen adults, so severely symptomatic as to be in heart failure, relieved and returned to a symptom-free life after operation, and children, of all ages, with moderate degrees of limitation of ability for exercise.

(slide) This slide is of a child of 10 months of age who had a frighteningly severe congenital stridor which disappeared on the operating table and has not returned since operation. The stridor had been so severe that from moment to moment the necessity for tracheostomy had been entertained.

Up to the present, we have operated upon 73 patients for pectus excavatum. With respect to the ages of the patients operated upon, we feel that the operation should be undertaken in infants or children whenever the deformity is judged deep enough to merit operation, or whenever it has been observed to be progressive. In adults, we have operated only upon patients who are symptomatic. As you see from the slide, we have operated upon 9 children under the age of 12 months and a total of 23 under the age of 2 years. We have not observed any particular difficulty in operating upon these infants and find they tolerate the operation at least as well as the older patients. We have not required tracheostomy in any cases. We have operated upon 43 patients between the ages of 2 and 20, and upon 7 patients between the ages of 20 and 41. All the latter were symptomatic, several of them severely so, and all obtained complete relief following operation.

The cosmetic end result in children has always been satisfactory, although in some of the earlier cases, when we did not overcorrect them as much as we do now, the chest was not as full and round as we would like to see it. The cosmetic result in the adults has been less satisfactory and is limited by the fact that the manubrium itself is depressed, and that actually the clavicle seemed to be pointing backward and medially so that the forward corrective displacement of the body of the sternum is limited by the position of the manubrium.

With respect for the etiology of the deformity, we have assumed it to be due to overgrowth of costal cartilages. I show you this slide of a child with congenital absence of the abdominal musculature. This is essentially a preparation in which the pull of the diaphragm is unopposed by the rectus and may be considered comparable to an otherwise exaggerated pull of the diaphragm. Here, at 3 months, you see no striking deformity of the sternum but, in the next slide, at 3 years of age, the distal end of the sternum is pointing sharply back where it has been pulled by the unopposed diaphragm. There is no sternal concavity. Furthermore, in many children with pectus excavatum the maximal depression is some distance cephalad to the insertion of the diaphragm.

From the standpoint of technique, we continue to exercise all of the deformed cartilages subperichondrially for the full extent of their deformity, to transect the first normal cartilage which is left behind, and to perform the sternal osteotomy at the interspace above this. This permits a three-point fixation: (1) across the sternal osteotomy, and (2) and (3) the resuturing of the transected cartilage. This produces a very firm fixation of the sternum and neither in infants nor in adults have we had to employ either external fixation or any form of strut.

I would suggest that perhaps the most important thing which has emerged from this morning's discussion is that today, in contrast with the situation at the time when Dr. Ochsner and Dr. DeBakey wrote their basic review, the situation is not whether these children should be operated upon, but when and how.

DR. LYMAN A. BREWER III, Los Angeles, Calif.—I have enjoyed the authors' presentation of these papers on pectus excavatum very much. We have been interested in this problem for a number of years and have carried out extensive cardiorespiratory tests including cardiac catheterization to determine the functional impairment. Our studies in a series of more than 60 patients reveal the fact that in the vast majority of cases, pectus excavatum is not a physiologically disabling condition. Although infants are difficult to test, there are very few infants and young children that show signs and symptoms of fatigue. Even in some of the teen-age patients and adults who have had moderate dyspnea, palpation, and fatigue on exertion, careful physiologic testing has not shown functional impairment of moment. Therefore, in our experience, the vast majority of operations that are being performed are carried out for psychological and cosmetic reasons. In the teen-age child, psychological and cosmetic reasons may be most important. Because teen-agers do indulge in sports and develop complexes out of all proportion to the physiologic impairment, surgical correction for the marked deformity is very definitely indicated. In those patients who have symptoms of cardiorespiratory deficiency, there is added reason for surgery.

We have employed an operative technique which makes all casts, external traction, temporary foreign bodies, splints, or fixation unnecessary. In this technique, we remove perichondrally the deformed cartilages and subperiosteally the osseous portion of the deformed part of the sternum down to the posterior periosteum. A cardiolysis is carried out if there is displacement of the heart. The posterior periosteum of the sternum, which is an exceedingly tough, dense structure, is pulled upward by the muscle pull of the pectoralis major muscles by fixing the pectoralis fascia to the posterior periosteum of the sternum with a midline row of interrupted heavy cotton or silk sutures. No internal nor external splint or traction is thus needed. To increase the rapidity of sternal regeneration, bone chips of the resected sternum are placed in the periosteal bed. There is practically no paradoxical movement once the closure of the chest wall has been completed and the chest wall is completely flat with the deformity corrected as soon as the operation has been completed. The patient coughs and breathes well. The patient is up and about in a few days and may be discharged home in from 7 to 10 days following the operation. The postoperative period is usually very smooth, without serious complications or prolonged morbidity. The sternum is usually solid in from 6 to 8 weeks. It is important, of course, that the patient maintain good posture during the period of sternal regeneration, as it is for all types of sternoplasty. The shortened and simplified postoperative care without the necessity for long periods in casts with external traction or with external internal splint, the excellent immediate cosmetic result, and the improved physiologic functioning of the thoracic cage commend the above technique for adults and children alike. We rarely operate upon infants and young children unless there is definite evidence of physiologic impairment, as pointed out by Dr. Ravitch.

DR. LAURENCE K. GROVES, Cleveland, Ohio.—The general practitioner and the pediatrician seem to be inclined to tell the parents of these children not to do anything about the deformity, it will probably go away. The only trouble with this advice is that it is not true; if anything, the deformity gets deeper with growth. We agree with most of the discussers of these papers this morning that frequently patients do have symptoms; however, it is usually difficult to demonstrate objective cardiopulmonary changes. In addition, more often than not these people will not have otherwise well formed chests and I think it is important to discuss with the parents the fact that we can cure the deformity, but that the child will still have a flat chest.

(slide) Here is a preoperative picture of a typical child we would operate upon.

(slide) We do essentially the same operation that has been described, but maintain external traction with rubber bands to a wire frame taped to the anterior chest. In children, this is necessary for only a week or two.

(slide) In the adult it is a little harder to attach the frame to the chest and it is incorporated in a light plaster body jacket.

(slide) Traction is maintained ordinarily from 4 to 6 weeks.

(slide) We have had the same experience in infants as cited by Dr. Ravitch. Here is a 12 week old infant who had severe stridor. At rest, there was actually no deformity, but on inspiration there was tremendous retraction. Nothing was actually done to the pectus, but traction sutures were placed in the sternal cartilage and traction maintained for approximately 2 weeks. There was no further respiratory distress.

DR. RICHARD H. OVERHOLT, Boston, Mass.—Dr. Welch and the previous discussers have indicated that results in the repair of this deformity can be improved by, first, a careful selection of patients and, second, by simplification of the technique of the operation. There seems to be general agreement that older patients some form of temporary fixation or support to the elevated sternum is desirable. Our experience has been largely with adult or adolescent patients. Recently, I have provided internal fixation by inserting a Steinmann pin from one side of the cage to the other and beneath the sternum. Both ends of the pin are threaded to accept a metal washer which can be turned into proper position. They prevent lateral movement of the pin. The period of hospitalization averages under 2 weeks. The pin can be removed easily as an office procedure 2 to 3 months later. This method is simple, safe, and effective.

DR. JAMES E. DAILEY, Houston, Texas.—I will take only a moment. Our experience with the strut in the majority of cases has been with children between the ages of 4 and 7. I would like to show you the youngest one who was 30 months old.

(slide) This is the child 10 days postoperatively.

(slide) This slide illustrates the rib strut wired in place.

(slide) The catheter you see in at the upper right leads to the space beneath the sternum and is placed there for about 24 to 36 hours to get rid of the fluid and dead space beneath the sternum.

DR. WELCH (Closing).—I would like to thank the discussers for their interest and the helpful information added to the subject of ''pectus excavatum deformity.'' There are just one or two closing comments that I would like to make.

The problem of recurrence has perplexed us. We have encountered this complication five times. It does not occur in the immediate postoperative period when external traction devices are used. It does not even occur in the first month when internal stabilization with a Kirschner wire is used. All patients appear satisfactory up to 3 months. When you see them 6 months to a year after operation, there, unexpectedly, is the patient with recurrence.

The second comment has to do with the type of operation. I have a very healthy respect for the risk associated with surgical correction of this disease, especially in the younger group. I believe that the more extensive operations involving a complete takedown of the anterior chest wall, with violation of both pleural cavities, will set the stage for major pleural cavity and mediastinal complications. I doubt that 50 consecutive operations of this type can be carried out without a mortality. Consequently, we feel that a simple external operation, of the type illustrated today, is preferred. A satisfactory thoracoplasty result is attained with virtually no postoperative complications.

The third comment has to do with late troubles. This has been adequately documented in the second and third decades of life. They do not develop clinically and cannot be objectively identified in the first decade. For this and for the other reasons presented, we recommend that operation be undertaken in selected individuals at or near the age of 3.

DR. GWATHMEY (Closing).—On behalf of Dr. Adkins and myself, I would like to thank the discussers. We agree with Dr. Dorner that the operative time is shortened by the use of preserved ribs in place of fresh bone. Recently, we have been using struts made of stainless steel and notched at both ends for fixation in the experimental animal. At the present time, tissue reaction has been minimal and there has been no problem with infection. We hope to report on this at a later date.

HYPOVENTILATION, HYPOXIA, AND ACIDOSIS OCCURRING IN THE ACUTE POSTOPERATIVE PERIOD

R Maurice Hood, Commander (MC) USN (by invitation), and
Arthur C Beall, Jr , Lieutenant (MC) USNR (by invitation),
Oakland, Calif
(Sponsored by Frank A Gerbode, M D , San Francisco, Calif)

ADEQUATE VENTILATION during thoracic operations has long been the goal of surgeons and anesthesiologists Crafoord seems to have been among the first to realize the importance of adequate ventilation as opposed to that required to maintain life during open chest operations Acidosis during anesthetic administration and surgical procedures is not a newly recognized phenomenon Austin and co workers,[1] in 1922, Cullen and associates,[2] in 1924 Stehle and Bourne,[3] in 1924, and Leigh,[4] in 1942, have all observed acidosis and a rise in pCO_2 following the administration of general anesthetic agents However the importance of acidosis during surgical procedures and its frequency and severity do not seem to have been appreciated until the work of Beecher[5] was reported before this group in 1949 Subsequently, numerous studies have been done the most notable among which have been the work of Gibbon and co workers,[6] Ellison, Ellison, and Hamilton,[7] Miller and associates[8] Stead Martin and Jensen,[9] and Taylor and Roos[10]

These investigators have clearly shown that hypoventilation is responsible for CO_2 retention with the development of respiratory acidosis Attempting to prevent this phenomenon, much work has resulted in methods and efficiency of ventilation during intrathoracic procedures far superior to those available 15 years ago

Little investigation has been directed toward respiratory efficiency during the immediate postoperative period In Gibbon's study[6] (1950), 11 patients had blood samples drawn 1 to 2 hours postoperatively, of the 11 cases, 2 showed a decrease in pH after surgery and, in 1 patient, O_2 saturation dropped to 78 per cent

Martin and Stead,[11] in 1953, removed blood samples in 18 patients 20 to 30 minutes after the patient had been returned to the ward All but 1 of these

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showed a pH drop from the preoperative level but since no samples were taken at the end of surgery, the respiratory efficiency of the postoperative period alone could not be evaluated. However, their mean values of CO_2 excretion and alveolar ventilation do not indicate hypoventilation in the group as a whole.

Sealy, Young, and Hickham[12] reported 2 patients, both of whom had respiratory acidosis in the postoperative period, possibly aggravated by the administration of oxygen. Respiratory assistance with other measures were used to relieve these patients.

Hamilton and Devine[13] determined pCO_2 from alveolar air and measured minute volumes in 100 surgical patients. No reference is made concerning the number of thoracic surgical patients included. Their studies indicated that 25 per cent of the total number had pCO_2 levels in excess of 45 mm. Twelve of 25 patients, with increased pCO_2 values, were shown to be hypoventilating in the recovery room.

We have been impressed with the apparent observation that thoracic surgical patients in the recovery room were hypoventilating; therefore, this study was undertaken to determine accurately the characteristics of ventilation during the first postoperative hour and to determine if hypoventilation was present in a sufficient degree to alter O_2 saturation, pCO_2 values, and pH of arterial blood.

METHOD

Thirty-eight patients were studied. Thirty underwent intrathoracic operations of miscellaneous types (Table I). Eight were individuals having major abdominal procedures. The subjects were not studied consecutively and no patient known or thought to have measurable respiratory insufficiency preoperatively was included.

TABLE I. TYPES OF OPERATIONS PERFORMED

TYPE OF OPERATION	NUMBER
Thoracic Surgical Patients	
Pneumonectomy	2
Lobectomy	5
Segmentectomy	6
Bronchoplasty	1
Mitral commissurotomy	4
Closure, atrial septal defect	1
Resection, mediastinal tumor	2
Vagotomy	1
Cervicodorsal sympathectomy	2
Resection of chest wall tumor	3
Pleurectomy	2
Exploratory thoracotomy	1

An arterial blood sample was obtained on the day prior to operation, and at the end of the procedure an intra-arterial needle was inserted into a femoral artery. Samples were obtained just prior to the removal of the intratracheal tube and at 15-minute intervals for 1 hour. Samples were analyzed for O_2 content and capacity after the method of Van Slyke and Stadie[14]; CO_2 content was determined following the method of Van Slyke and Neill.[15] These were converted to serum content values using the system of Van Slyke, Sendroy, and Liu[16] Serum CO_2 tension in millimeters of mercury was calculated, using the nomogram of Van Slyke and Sendroy[1] Heparinized blood samples were collected in pipettes containing sodium fluoride, as suggested by Craig and coworkers,[18] and the pH was determined directly, using a Cambridge glass electrode pH meter *In addition, spirograms of 2 minute duration were made on* each patient, to coincide with each of the 4 blood samples drawn in the post*anesthetic period From these, tidal volume and minute ventilation volumes* were measured Alveolar ventilation was estimated using the values for anatomic dead space determined by Fowler[19]

Anesthesia in this group of patients was conducted by 2 anesthesiologists and 3 residents in anesthesiology, who were uninformed as to the purpose or results of the study Pre anesthetic medication usually consisted of Demerol pentobarbital, and atropine, occasionally morphine and scopolamine were used

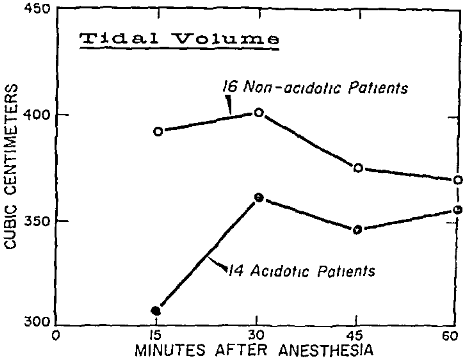

Fig 1 —Comparison of the relationship between the mean values for tidal volume in 14 thoracic surgical patients who acquired acidosis in the postoperative period with 16 who did not show this phenomenon

Anesthetic agents employed were usually intravenous Pentothal Sodium for induction *and nitrous oxide and oxygen inhalation supplemented by intravenous* succinylcholine hydrochloride for the duration of the procedure Cyclopropane and ether were used in a few patients Controlled respiration was used in all thoracic cases, in 16 patients this was carried out by manual compression of the anesthetic bag and, in 14 patients, controlled ventilation was administered by the Jefferson ventilator with intermittent positive negative pressure

RESULTS

Table II gives the data acquired on the total series of patients From this material, 14 patients in the thoracic series were identified as demonstrating a drop in pH of at least 0 10 unit during the first postope
of the other 16 showed lesser changes, no change, or a

TABLE II. DATA ON 38 PATIENTS S

				ARTERIAL O_2 (% SATURATION)						ARTERIAL pCO_2 LEVELS (MM. HG				
CASE NO.	NAME	SEX	AGE	PREOPERATIVE CONTROL	END OF ANESTHESIA	INTERVALS (MIN.)				PREOPERATIVE CONTROL	END OF ANESTHESIA	INTERVALS (M		
						15	30	45	60			15	30	45
Thoracic Surgery														
1	L. S.	M	30	90	100	100	95	94	91	35	42	43	42	--
2	N. J.	M	27	98	100	89	92	93	93	33	27	40	46	52
3	O. O.	M	57	87	100	97	91	--	86	35	38	43	42	--
4	E. C.	M	39	90	90	90	92	91	88	38	44	48	47	49
5	G. D.	F	39	92	100	100	82	93	88	29	32	58	49	44
6	M. E.	F	14	91	100	92	94	96	91	29	38	45	42	52
7	G. H.	M	62	91	100	89	82	87	78	30	35	46	34	38
8	P. P.	M	42	91	100	76	91	90	89	35	28	54	52	56
9	I. B.	M	33	96	100	87	86	88	86	46	33	46	48	47
10	W. S.	M	35	92	100	88	86	87	84	45	32	42	50	49
11	E. E.	F	31	94	95	100	92	94	95	36	45	39	52	44
12	D. M.	M	43	94	100	88	89	89	87	31	33	42	--	--
13	R. H.	M	37	91	100	98	91	87	89	42	51	46	45	42
14	E. L.	M	54	86	99	97	95	95	90	37	34	53	40	--
15	R. H.	M	35	91	100	97	97	100	98	34	39	46	43	45
16	D. M.	M	22	88	100	94	96	97	93	52	34	48	48	46
17	T. D.	M	20	91	100	100	100	97	98	37	51	45	47	44
18	A. B.	M	19	93	100	100	100	97	85	52	36	38	37	36
19	O. B.	M	39	89	95	85	87	91	89	35	59	41	46	--
20	E. R.	M	39	88	100	88	91	91	89	32	40	40	45	37
21	G. M.	F	38	93	100	91	89	--	86	32	37	30	42	--
22	E. W.	F	26	96	100	98	91	96	89	32	39	48	42	40
23	W. D.	M	32	95	100	--	100	98	99	34	42	--	40	44
24	J. R.	M	19	92	71	78	78	74	80	34	86	58	58	46
25	R. E.	F	26	93	92	84	86	86	76	32	43	74	80	67
26	V. H.	F	35	98	100	96	98	95	94	41	31	32	35	33
27	R. M.	M	49	--	100	88	83	90	99	--	36	33	33	22
28	J. S.	F	22	90	100	98	100	97	95	40	37	46	46	47
29	W. C.	M	33	93	100	93	95	92	95	--	53	49	44	39
30	L. H.	M	26	94	100	91	82	94	91	42	35	44	50	41
Abdominal Surgery														
31	M. K.	F	31	90	100	59	92	--	--	37	45	36	48	--
32	M. S.	M	59	87	100	100	97	88	85	36	51	49	45	38
33	A. S.	F	46	89	100	95	98	96	94	32	32	32	36	35
34	C. N.	M	36	91	100	99	94	90	91	41	46	49	51	44
35	C. M.	M	22	94	100	98	100	93	93	45	42	43	48	31
36	J. S.	M	30	94	100	100	100	95	95	27	50	35	42	37
37	D. R.	M	52	91	100	95	93	96	98	39	28	33	28	29
38	L. K.	M	26	91	100	98	94	97	97	35	41	35	34	35

*Jefferson.

†Recovery room.

acquired during the period of anesthesia. The spirograms and ventillatory values of these groups of patients were studied individually and mean values for the group calculated. Fig. 1 compares the mean tidal volumes of the 2 groups at 15-minute intervals and clearly indicates significantly lower values for the patients in the acidotic group. Some individual values were measured in which the tidal volume was as low as 150 c.c.

Fig. 2 is a similar comparison of the mean values for minute ventilation of the same 2 groups. These values show an even greater divergence and, in addition, illustrate the usual trend toward normal values for patients in the depressed group as the time after anesthesia progressed.

Alveolar ventilation is without doubt the most important measurement

URING THE IMMEDIATE POSTOPERATIVE PERIOD

ARTERIAL pH VALUES								
PREOPERATIVE CONTROL	END OF ANESTHESIA	INTERVALS (MIN.)				VENTILATOR* USED	NASAL O2 GIVEN IN P.P.†	PROCEDURE
		15	30	45	60			
7.43	7.31	7.29	7.32	7.35	7.34	yes	yes	Pleurectomy
7.35	7.37	7.32	7.28	7.22	7.26	yes	no	Sympathectomy, upper dorsal
7.42	7.40	7.28	7.28	–	7.37	no	yes	Wedge resection, LUL
7.42	7.35	7.33	7.31	7.30	7.30	no	yes	Bronchoplasty, left main
7.48	7.43	7.22	7.28	7.32	7.32	no	yes	Mitral commissurotomy
7.47	7.43	7.33	7.36	7.28	7.37	no	yes	Segmentectomy, RUL
7.51	7.40	7.32	7.43	7.40	7.36	yes	yes	Lobectomy, LLL
7.36	7.43	7.23	7.24	7.20	7.21	no	no	Transthoracic vagotomy
7.34	7.42	7.31	7.28	7.28	7.28	no	no	Wedge resection, RUL
7.39	7.44	7.32	7.28	7.29	7.31	no	yes	Closure atrial septal defect
7.46	7.29	7.31	7.24	7.30	7.29	no	no	Resection mediastinal tumor
7.43	7.33	7.29	--	--	7.23	yes	no	Segmentectomy, LUL
7.40	7.29	7.33	7.35	7.37	7.36	no	no	Lobectomy, LUL
7.43	7.48	7.26	7.40	--	7.39	yes	yes	Pneumonectomy, right
7.47	7.38	7.30	7.34	7.34	7.31	yes	no	Resection mediastinal tumor
7.29	7.46	7.33	7.34	7.36	7.35	yes	yes	Lobectomy, RU & ML
7.44	7.32	7.37	7.35	7.37	7.37	no	yes	Excision chest wall tumor
7.31	7.43	7.40	7.41	7.41	7.42	yes	yes	Segmentectomy LUL
7.43	7.31	7.39	7.32	--	7.38	no	yes	Sympathectomy, cervicodorsal
7.53	7.38	7.35	7.32	7.42	7.41	yes	yes	Pleurectomy
7.40	7.32	7.41	7.26	--	7.44	no	yes	Mitral commissurotomy
7.47	7.29	7.20	7.27	7.31	7.33	yes	yes	Segmentectomy RLL
7.49	7.37	7.32	7.39	7.34	7.34	no	yes	Segmentectomy LLL
7.50	7.13	7.28	7.27	7.36	7.33	no	yes	Lobectomy LLL
7.48	7.20	7.02	7.02	7.09	7.12	no	yes	Lobectomy ML
7.36	7.46	7.40	7.38	7.40	7.48	no	yes	Mitral commissurotomy
--	7.46	7.45	7.41	7.52	7.29	no	yes	Exploratory thoracotomy
7.37	7.39	7.31	7.31	7.30	7.34	yes	yes	Pneumonectomy left
--	7.23	7.26	7.32	7.32	7.33	yes	yes	Mitral commissurotomy
7.38	7.39	7.35	7.32	7.36	7.34	yes	no	Excision chest wall tumor
7.37	7.26	7.42	7.23	7.23		no	part time	Cholecystectomy
7.40	7.35	7.30	7.34	7.40	7.28	no	yes	Cholecystectomy
7.49	7.41	7.43	7.38	7.40	7.41	no	no	Colectomy, right
7.37	7.30	7.28	7.25	7.30	7.32	no	yes	Gastrectomy subtotal
7.34	7.37	7.34	7.27	7.52	7.26	no	yes	Exploratory laparotomy
7.53	7.24	7.37	7.32	7.39	-	no	yes	Cholecystectomy
7.32	7.51	7.42	7.48	7.48	7.48	no	no	Abdominoperineal resection
7.39	7.33	7.36	7.38	7.36	7.39	no	yes	Gastrectomy, subtotal

when evaluating adequacy of ventilation. The methods of determination vary, depending upon the method used in estimating dead space. For a study such as this to have practical value, the more elaborate methods of estimating physiologic dead space would have to be discarded. As previously stated, the writers have chosen to use the normal values for anatomic dead space recorded by Fowler.[19] The values so obtained were included in the formula, tidal volume minus dead space times rate equals alveolar ventilation. At low tidal volume values, Briscoe, Forster, and Comroe[21] have shown that this formula is not strictly applicable because the moving column of air in the tracheobronchial tree moves as a conical front and therefore some alveolar ventilation occurs even when tidal volumes are less than the calculated dead space. However, the estimated values so determined are more indicative [illegible] the tru[illegible] us of the patient's ventilation than either tidal volume or minute ventilation values. Fig. 3 illustrates the mean alveolar ventilation values in the 2 groups previously compared. Again there is a significant difference in the two series.

The spirograms of individual patients graphically demonstrate the inadequacy of ventilation better than the values just discussed. There is considerable individual variation, as will be noted in Figs. 4 and 5. Inadequate ventilation resulted from low tidal volume, decreased rate, or from gross irregularity with periods of apnea as long as 25 to 30 seconds.

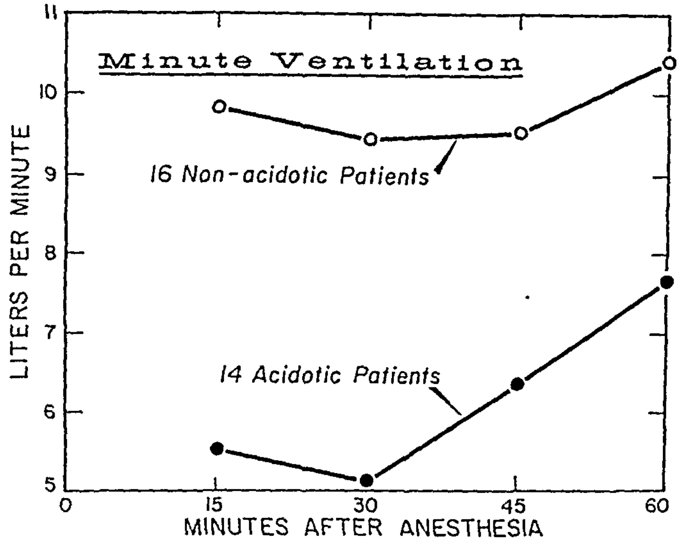

Fig. 2.—Comparison of the relationship between the mean values for minute ventilation in 14 thoracic surgical patients who acquired acidosis in the postoperative period with 16 who did not show this phenomenon. In addition to the obvious depression of the acidotic patients, the trend toward improvement during the hour of observation should be noted.

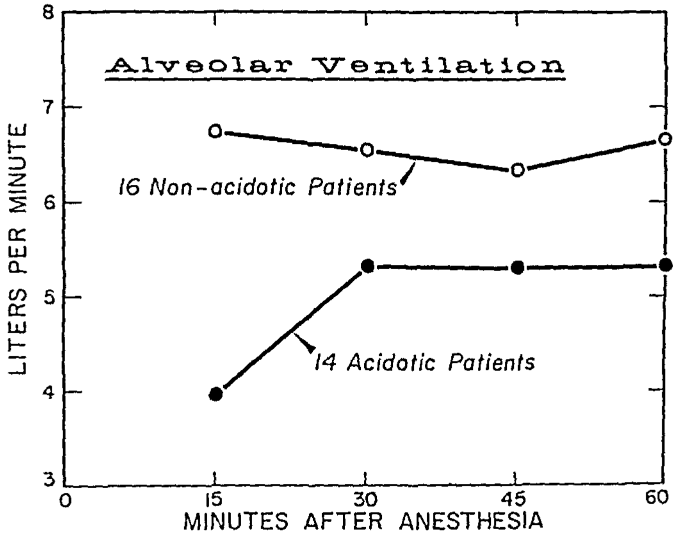

Fig. 3.—Comparison of the mean values from the estimation of alveolar ventilation in the 2 groups of patients compared in Figs. 1 and 2, and again showing an obvious difference, particularly in the first 15-minute period.

Hypoxia, although present in minimal degrees in several patients, was largely prevented by the use of O_2 by nasal tube in the recovery room. However, O_2 saturation dropped to levels as low as 75 per cent in 2 patients who were receiving O_2, in these, the tidal values were at ranges from 150 to 255 c.c.

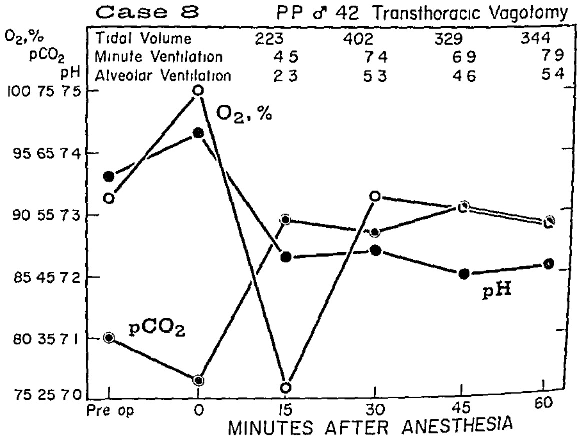

Fig 4.—The total values obtained in Case 8, showing the development of respiratory acidosis and hypoxia during the recovery room period

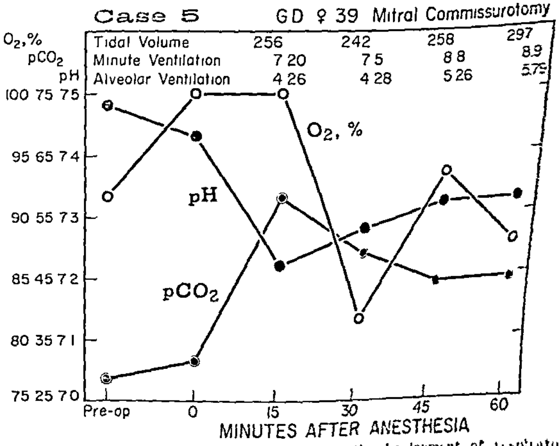

Fig 5.—Values obtained in Case 5, again showing the development of respiratory acidosis and hypoxia coincident with low tidal volumes

Evaluation of the effect of the use of the Jefferson ventilator of 14 patients in whom it was used, 7 fell into the acidotic gr nonacidotic group. These figures indicate that the method of v surgery had no effect on postoperative respiration. An incidental observation was that no patient in whom the Jefferson ventilator was used had marked acidosis at the end of surgery whereas there were 2 patients with pH levels of 7.20 or lower, who were ventilated manually. There appeared to be no correlation between the duration of the period of anesthesia and the incidence of respiratory depression.

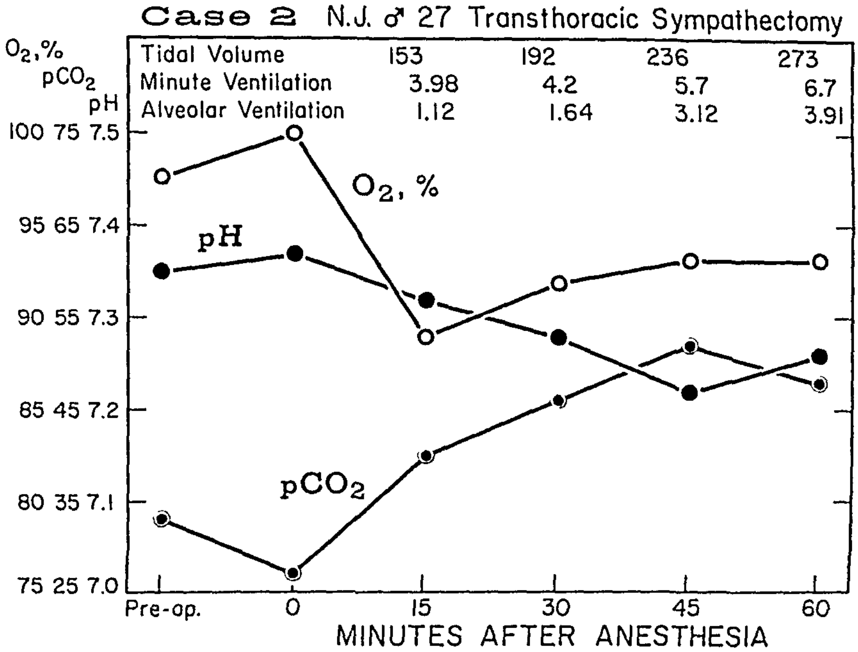

Fig. 6.—The values obtained in Case 2, demonstrating increased levels of pCO_2 and lowering of pH over a much longer period, in comparison with the 2 cases in Figs. 4 and 5.

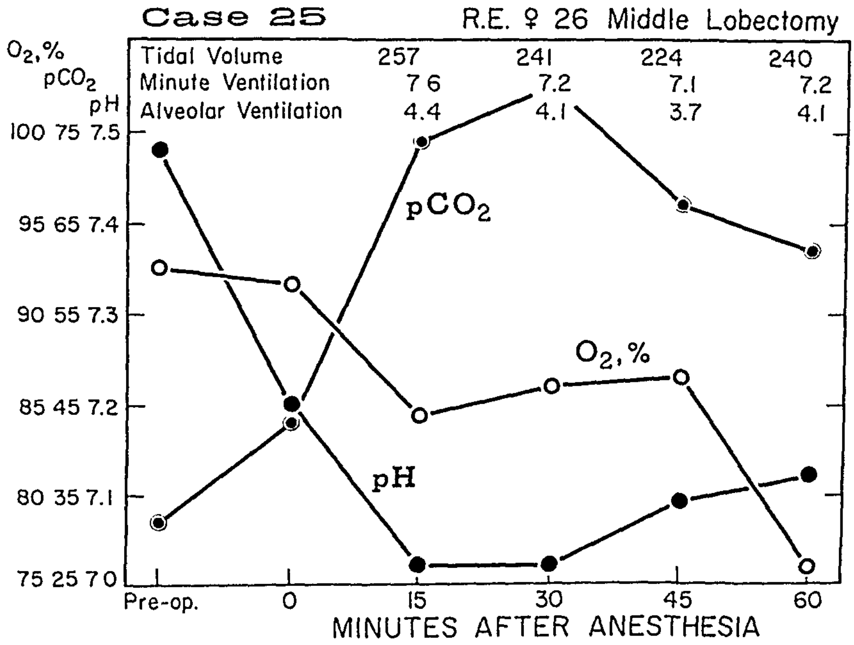

Fig. 7.—Values obtained in Case 25, the patient demonstrating the most marked deviation from normal values of any patient in the entire group. She acquired acidosis during the operative period; however, during the postanesthetic period, the pCO_2 levels arose to 80 mm. Hg and the pH dropped to 7.02.

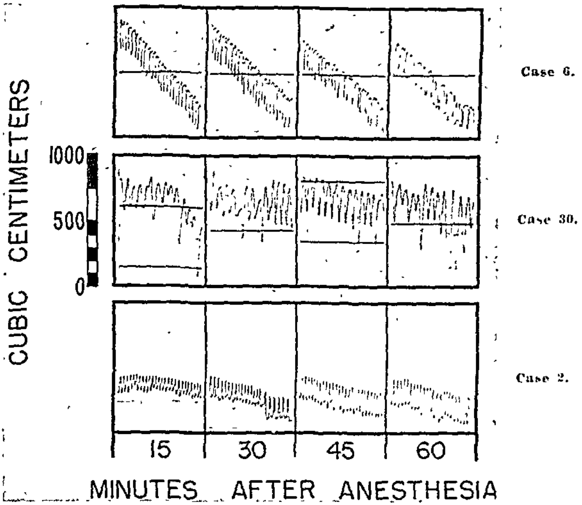

Fig. 8.—Sample spirograms from 3 patients in the acidotic group, showing generally low tidal volumes and gross irregularity in volume from breath to breath (note Case 30). In Case 2, a more commonly occurring situation may be seen—shallow, rapid, regular respiration in which the tidal volume gradually increased during the hour of observation.

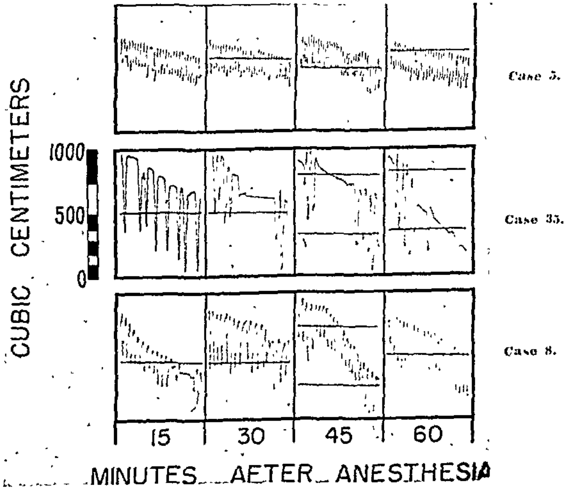

Fig. 9.—Sample spirograms of 3 other patients in the acidotic group. [illegible] the long periods of apnea occurring in Case 35.

Figs. 4, 5, 6, and 7 are graphic demonstrations of the total values in 5 patients who were in the acidotic group.

Figs. 8, 9, and 10 are reproductions of the spirograms produced by 9 patients who became acidotic during the recovery room period.

DISCUSSION

Obviously the data obtained in this study are referable only to patients given one method of anesthesia by one group of anesthesiologists and therefore conclusions reached do not necessarily apply to all thoracic surgical patients. However, it would seem reasonable to assume that similar situations frequently prevail, and particularly so in patients with disease states impairing pulmonary function.

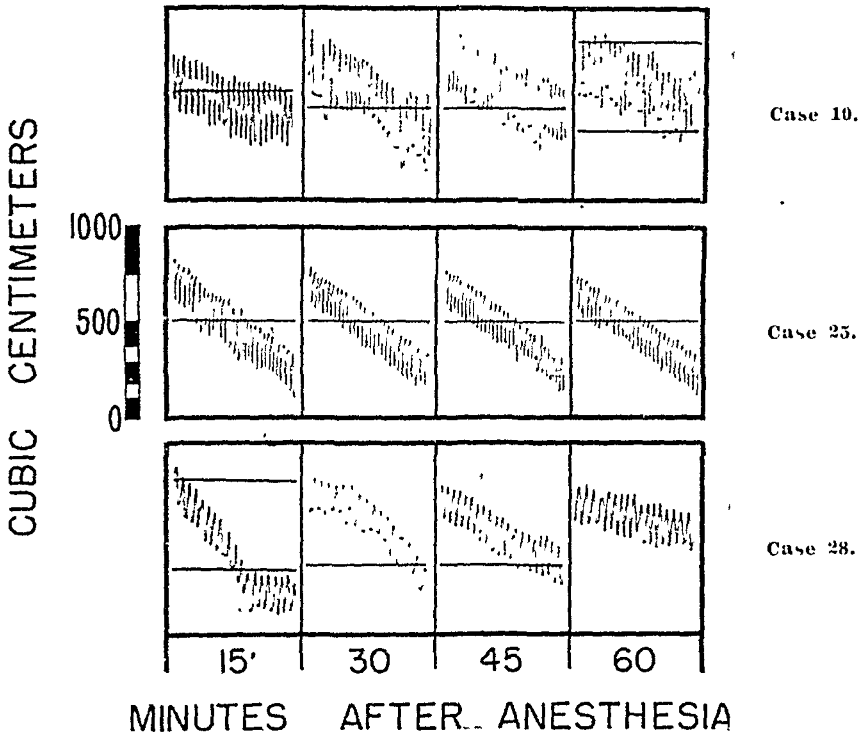

Fig. 10.—Sample spirograms of 3 other patients who became acidotic during the period of observation and showing the low tidal volumes, particularly in Cases 25 and 28.

The causes of respiratory depression in the immediate postanesthetic period are not easily separated or identified. It is possible that preanesthetic medication still may be effective during this period. The anesthetic agents certainly do not terminate their effect immediately upon cessation of their administration. In the series of Hamilton and Devine,[13] the greatest number of patients who were hypoventilating were those receiving nitrous oxide, Pentothal, and relaxants. A majority of the patients in this series were similarly anesthetized. However, this is not considered sufficient evidence to incriminate the agents used. Postoperative pain may be and probably is a factor; however, it was noted in this group of patients that as the hour of observation passed and pain apparently increased, ventilation improved, also, that narcotics administered to relieve pain did not improve ventilation and occasionally appeared to impair it further.

It is noted that respiratory depression in this series was chiefly confined to those having chest operations. One obvious difference in the two groups other than the surgical procedure, was the greater use of controlled respiration in those having thoracic procedures while the abdominal surgical patients were not rendered apneic for as prolonged periods as those with chest operations. All anesthesiologists are familiar with the fact that patients who have been in an apneic state resume normal respiration gradually and occasionally quite slowly. Whether or not this mechanism was still acting in the first operative hour was not determinable.

Whatever the cause or causes of respiratory depression, the resultant CO_2 retention and acidosis are considered of serious import even though they might occur only occasionally. Hypoventilation in patients with preoperative respiratory insufficiency, such as might be the case with emphysema or any other advanced parenchymal disease, might seriously affect the patient's chances of survival.

Certainly, sufficient experimental and clinical investigations have shown the lethal hazard of hypercapnea, particularly when associated with even a brief period of hypoxia. The fact that no patient in this series suffered any apparent ill effect from the abnormal acid base balance indicates again the often demonstrated ability of the human organism to withstand physical trauma.

The practical application of this study should be an attempt at prevention or correction of hypoventilation. To anesthesiologists the idea of having the patient recover from the effect of the anesthetic agents as soon as possible after the termination of surgery is not a new one. However despite the fact that by the end of the first 15 minute period, every patient in this series had recovered sufficiently to obey simple commands and reject a mouth airway, the respiratory function was still impaired. Referring again to Table II, it will be noted that the majority of the hypoventilatory patients were in the first half of the series. As the anesthesiology department gradually became aware of the purpose of the study, more strenuous efforts to effect more complete and rapid recovery were made. Whether or not stimulating drugs are indicated for this purpose is controversial.

It is well known that hypoxia during hypoventilation can be largely prevented by the use of oxygen by almost any method. The results of this investigation bear this out. Despite the general recommendations for the use of oxygen during anesthetic recovery, the recovery room personnel were frequently found to be careless in its use, particularly if the patient was awake, not cyanotic, and in no apparent distress. No patient in the entire group gave any clinical indication of the abnormal physiologic state. There were no episodes of hypotension, no arrhythmias, and no cyanosis except in one individual who vomited and aspirated mucus. Therefore, the diagnosis of respiratory acidosis and hypoxia is not clinically feasible unless special apparatus for measuring alveolar CO_2 and O_2 saturation are available. However, hypoventilation can be detected once the recovery room personnel are cognizant of respiration in terms other than rate and cyanosis. Numerous devices are available which are capable of measuring tidal volume, one of which (a basal metabolism machine) is available in most hospitals. The nursing staff can be easily taught to measure tidal volumes and to realize that values under 350 c.c. or rates under 15 per minute require notification of the anesthesiologist or surgeon.

Correction of hypoventilation may be accomplished most easily by assisted respiration which again may be administered by several means. Assistance with the bag of the anesthesia machine or the use of intermittent positive pressure valves such as the Bennett are most practical.

SUMMARY

1. The respiration of 38 patients—30 having had thoracic operations and 8 having had major abdominal operations—has been studied by spirograms made at 15-minute intervals for 1 hour after discontinuance of anesthesia. Arterial blood samples were taken at the same intervals and the O_2 saturation, pCO_2 levels, and pH values determined.

2. Fourteen of the 30 patients undergoing thoracic surgery were found to be hypoventilating to a degree sufficient to lower pH by at least 0.10. The pCO_2 values were correspondingly elevated.

3. Minimal to moderate degrees of hypoxia were also noted. Spirograms demonstrate hypoventilation and breathing irregularity. Possible mechanisms of respiratory depression are discussed. Emphasis on detection of hypoventilation and its correction by assisted respiration is suggested.

The authors gratefully acknowledge the technical assistance of Mrs. M. E. Hutchin, Chief Biochemist, and other members of the research laboratory and, also, the editorial assistance of Mrs. M. F. Jack, Clinical Investigation Center.

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DISCUSSION

DR. CLARENCE CRAFOORD, Stockholm, Sweden.—I [illegible] privilege of the floor. Last year, as some of you know, I [illegible] here to attend the meeting and I must say how glad I am [illegible] this year.

I think the questio[illegible] at has been raised is [illegible] cardiac surgery cases. [illegible] perative hypoventilation [illegible] fore, we follow them ve[illegible] refully in the postoperative [illegible] activity.

In the small grou[illegible] open heart cases that we have [illegible] has been a number of p[illegible] its in whom we have found [illegible] not adequate, and that [illegible] run into CO_2 accumulation [illegible] them with repeated test[illegible] tinuously during the first [illegible] tracheostomy is valuabl[illegible] all patients [illegible] taneously. We use an [illegible] ight [illegible] Engstrom respirator wh[illegible] takes over the patient's [illegible] respiration, as is done [illegible] paralytic cases [illegible] until we can measure th[illegible] the respiratory [illegible] a few hours; the longe[illegible] was ab[illegible] the respirator and be al[illegible] to breathe by himself.

We are quite conv[illegible] that many [illegible] the postoperative period [illegible] these [illegible]

DR. FRANK COL[illegible] SPENCER, [illegible] experiences with acidosis in surgical patients. [illegible] tions during the past 2 [illegible] ars as [illegible] operation under hypothermia or car[illegible] been failure of clinical findings to [illegible] are semiconscious; lower pH values [illegible] respiratory arrest. The most [illegible] warning, respiratory arrest may [illegible] clinical signs of acidosis, and [illegible] we think it is useful to measure the [illegible] tensive from unexplained causes. [illegible] thorax with mediastinal displacement [illegible] severe hypotension from hemorrhagic shock. The acidosis can be corrected with increased ventilation or intravenous sodium bicarbonate, 3 to 8 Gm., after which the underlying cause of the acidosis can be treated.

Like Dr. Crafoord, we have also come to increasing use of the respirator. It is particularly useful in patients with severe cardiac failure, and we have had some of these patients in a respirator for 3 to 4 weeks until they made a complete recovery.

DR. GEORGE H. A. CLOWES, Jr., Cleveland, Ohio.—I rise simply to emphasize the dangers of the acidosis described by Drs. Hood, Beal, and Gerbode. Uncompensated acidosis is a lethal affair if carried beyond a certain point. It renders the organism incapable of responding to superimposed stresses in the normal fashion. A series of experiments performed in our laboratory last winter by Miss Mary A. Hughes, a medical student, will serve to illustrate this. Acidosis was induced in dogs by the infusion of hydrochloric acid intravenously. Little or nothing occurred to the circulation until the arterial pH fell below 6.9 when heart failure usually took place. However, at arterial pH values ranging from 6.9 to 7.1, it was found that animals were quite incapable of responding to blood loss. They entered a state resembling ''irreversible'' or normovolemic shock from which they could only be recovered by the infusion of sodium bicarbonate.

(slide) Dr. Hood has demonstrated acidosis to be an immediate postoperative affair. The data from this patient, who happens to have had a circulatory bypass and cardiotomy, will serve to illustrate the course of events following any major thoracotomy. During perfusion there was some accumulation of lactic acid with a fall in CO_2. Two hours postoperatively the lactic acid had fallen and CO_2 was up slightly. Note that the following morning lactic acid was considerably elevated, probably due to the arterial oxygen desaturation (85 per cent) and a moderate impairment of cardiac function. Yet CO_2 was low and the arterial pH normal.

In our experience this is common. But if one finds an uncompensated acidosis with an accumulation of CO_2 as well as lactic acid, death will supervene shortly unless strenuous measures are taken to improve the respiration and the acid-base balance.

DR. RALPH ADAMS, Wolfeboro, N. H.—I wish to testify to the enormous practical importance of this presentation by Dr. Hood. It is applicable to all cases, not only as a method of study, but also as a guide to therapy. First, consider those cases which are complex; no one needs to have his attention directed to acidosis or hypoxia as a possibility in the complex case, such as a patient coming off the pump-oxygenator. But it is well to remember simpler situations, such as that of a patient who has a perforated ulcer closed surgically, and who is back in the ward 45 minutes after receiving his preanesthetic medication, because things went better than anticipated. His medication strikes him after he gets back and he does not breathe. Or the case of a patient being prepared for bronchoscopy, who has overreacted to the highly effective combination of narcotic, sedative, and tranquilizer one is currently using, and then he does not breathe. These are examples of simple cases; however, death ensues just as surely as it does in complex ones.

Second, one can recognize them as being close to trouble in a less complex way than by pH figures, fortunately. These are helpful and we like them, but one can watch the patient's breathing; it does not take a highly educated person to do it. We have found that ward aides are very good at telling whether patients are breathing or not. People generally are poor at recognizing cyanosis; if even suspected, our rule is to assume it to be present and to treat for it. Oximeters and Van Slyke analyzers will show scientifically what must be treated at onset, or even better, on suspicion.

Third, there are several ways by which one can assist the patient therapeutically. One need not be as scientific as is required in conducting excellent laboratory studies such as those we have heard about in this paper. Even the ward aide can help oftentimes those patients who are slightly acidotic, who are semiconscious, but who generally can be persuaded to breathe. If they cannot be persuaded to breathe, they require assistance. One remembers artificial respiration, and the numerous good ways of applying it. A little chest wall assistance for a few minutes often is all that is needed Then there is the demand valve, nurses can be taught to use this equipment as efficiently as the most highly trained physician The fact that there is no nurse or ward aide on my surgical wards who cannot use the demand valve, as well as the chief surgeon, I think has saved a number of lives Demand valves are not very expensive and are available in differing types from several manufacturers Suction can be applied intermittently to the thoracic wall and it moves the wall harmlessly when there is the long need for assistance that is required by some postoperative patients before they breathe spontaneously in adequate volume The Emerson combination of a plastic raincoat and vacuum cleaner is one extremely simple and almost hazard free way of giving such assistance

DR HOOD (Closing) —I would like to thank the discussers for their comments We certainly agree with Dr Clowes that this is not a short term problem The majority of our patients studied who were abnormal had little or no improvement in the first postoperative hour This observation has been made before, particularly by Bjork, who studied the respiratory deficiency one to 2 days following various surgical procedures and found the oxygen saturation still lowered after this time We would also like to emphasize that only in the larger hospitals and medical centers are there facilities for analyzing CO or determining pH We would agree with Dr Adams that detection of hypoventilation is a practical problem which even relatively inexperienced personnel can be taught to accomplish Numerous devices are available which can be used to measure tidal volume one of these, a basal metabolism machine, is present in most hospitals and can be used by nurses so this problem can certainly be solved without resorting to more complicated apparatus

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CHONDROSARCOMA IN THE POSTERIOR MEDIASTINUM

John J. Sullivan, Jr., M.D., and Joseph L. Mangiardi, M.D.
Bethpage, N. Y.

Cartilaginous neoplasms of the thorax are relatively common, nearly always grossly involve osseous structures (sternum, vertebra, or rib), and are most often malignant. O'Neal and Ackerman,[1] in a review of the clinical and pathologic aspects of these lesions, presented 96 cases including two chondrosarcomas which occurred in the posterior mediastinum causing rib destruction. In 1950, Weisel and Ross[2] described excision of a malignant cartilaginous tumor with hourglass involvement of the mediastinum and spinal canal. There was gross destruction of vertebral bodies, pedicles, and laminae, as well as rib heads. In 1956, Ringertz and Lidholm[3] reported one chondrosarcoma from a personal series of 155 mediastinal neoplasms and cysts. This was posterior in location, probably originating from a vertebral body, and recurred 2 years after excision. In 1956, Aronstam and his associates[4] described excision of a chondrosarcoma from the posterior mediastinum in 2 cases in which origin from a vertebral body was demonstrated. In each of the 6 foregoing cases, including those of O'Neal and Ackerman, gross destruction of cortical bone was demonstrated by x-ray studies or at operation.

The occurrence of a circumscribed chondrosarcoma in the posterior mediastinum without demonstrable attachment to bone, although rare, is exemplified by the following case.

CASE REPORT

F. E., a 26-year-old white housewife,* was admitted for evaluation of severe interscapular and left thoracic pain of 2 years' duration. The only associated symptoms were insomnia and a 10-pound weight loss due to anorexia, both secondary to the pain. There was no history of previous injury, familial disorder, or significant illness. The onset of pain 2 years previously had been gradual and intermittent, being located in the left interscapular area and more severe in the supine position. For about 1 year prior to admission it had been almost constantly present, tending to assume a radicular pattern on the left side, and had become progressively more intense, making her existence almost intolerable. She had consulted numerous physicians here and in Europe, and, in spite of quite elaborate studies, no organic lesion had been detected. One year prior to admission, x-ray studies of the chest at another hospital showed a definitely abnormal mediastinal shadow, but these roentgenograms

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Received for publication March 31, 1958.

*Referred by Dr. Harry Abe, Wantagh, N. Y.

had been interpreted as normal. Films of the spine and a myelogram done at this time showed no abnormality. Intercostal nerve blocks and an empirical course of x-ray therapy had given no relief, and she had been labeled as psychoneurotic.

Physical examination at this admission showed no abnormality except for slightly diminished breath sounds over the upper left posterior thorax. There were no stigmata of neurofibromatosis, and careful skeletal and neurological examinations were negative. She did not appear acutely or chronically ill.

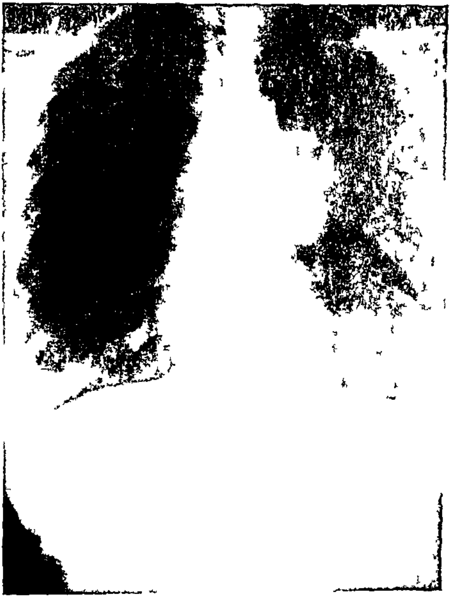

Fig 1.—Roentgenogram showing large circumscribed density in mediastinum extending into left hemithorax. Calcifications are visible especially near the center. A lateral film confirmed its posterior location.

Complete hematologic studies, blood chemical studies, and urinalysis were within normal limits.

Roentgenograms of the chest (Fig 1) showed a large, circumscribed, irregular density occupying the posterior mediastinum and left paravertebral gutter and extending into the left hemithorax just below the aortic arch. Finely scattered calcific densities were visible within the mass. There was no erosion of the spine. Fluoroscopy demonstrated the mass to be nonpulsating.

Exploratory thoracotomy was performed on June 20, 1957, using a left lateral approach and *fifth interspace incision*. A solid, circumscribed, bosselated tumor the size of a small grapefruit lay extrapleurally in the left vertebral gutter and posterior mediastinum. It was adjacent to the sixth, seventh, and eighth vertebral bodies and corresponding posterior ribs and to the descending aorta. The lung, pulmonary hilum, vagus and phrenic nerves were not involved. The mass was rather easily freed from the cl [illegible] ll remc [illegible] eriosteum of subjacent ribs with it. The costal cortex was nowhere e [illegible] soft tissue

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From the Department of Surgery, Mid-Island Hospital, Bethpage, N. Y.
Received for publication March 31, 1958.

*Referred by Dr. Harry Abe, Wantagh, N. Y.

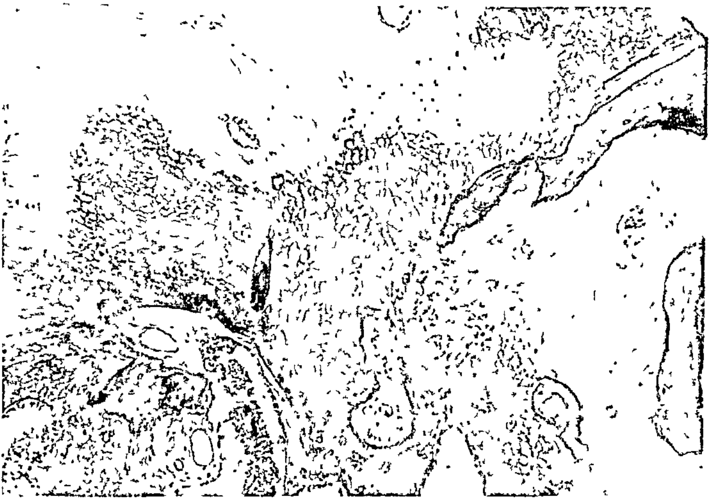

Fig 4 —Photomicrograph from central portion well-differentiated cartilage and bone (×100 reduced ¼)

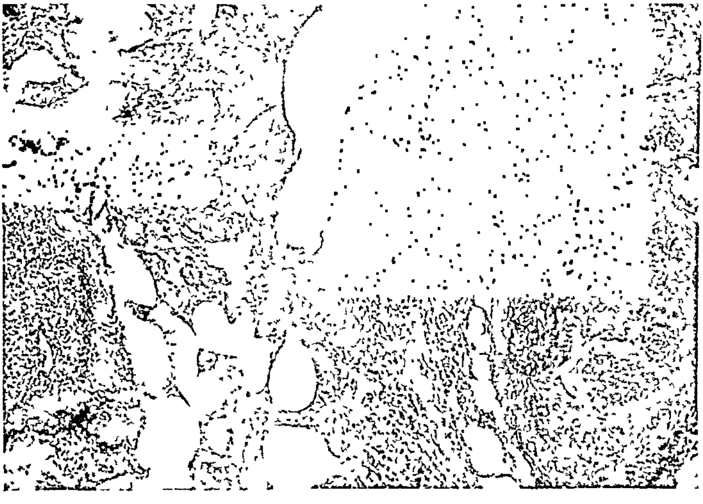

Fig. 5 —Photomicrograph from tumor showing transition zone. Note pleomorphism and irregularity of arrangement of cells This chondrosarcomatous pattern was found principally between central well-differentiated and peripheral undifferentiated areas. (×100; reduced ¼)

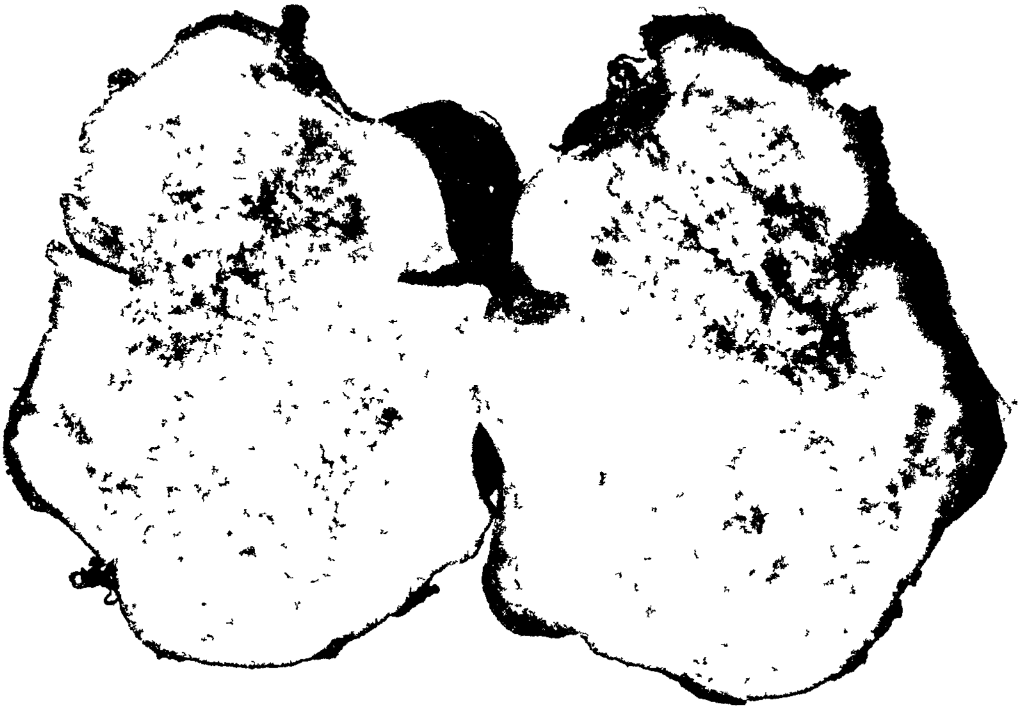

Fig. 2.—Cut section of excised tumor showing irregular calcific areas about the center surrounded by chondrosarcomatous tissue progressing to the smooth, firm, highly malignant "round cell sarcoma" at the periphery.

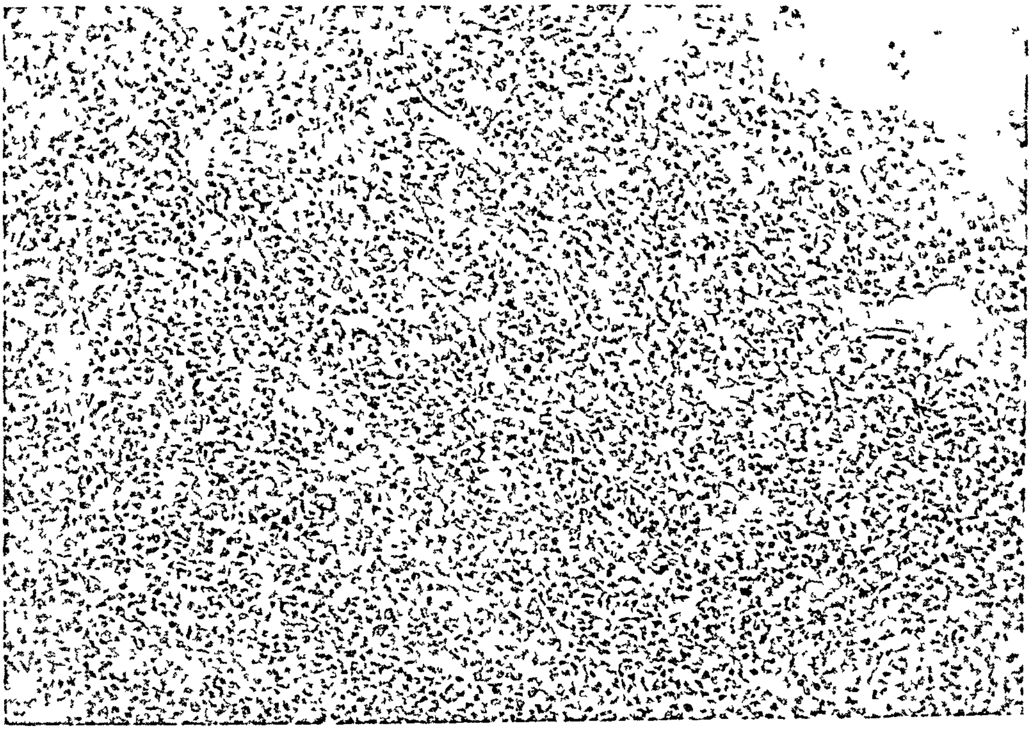

Fig. 3.—Photomicrograph of peripheral portion of tumor. Note highly undifferentiated and cellular tissue. (×200, reduced ¼.)

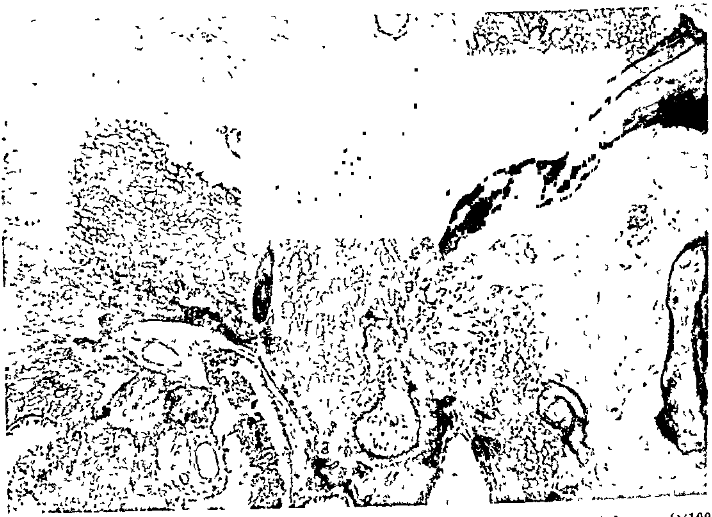

Fig. 4.—Photomicrograph from central portion well-differentiated cartilage and bone (×100; reduced ¼.)

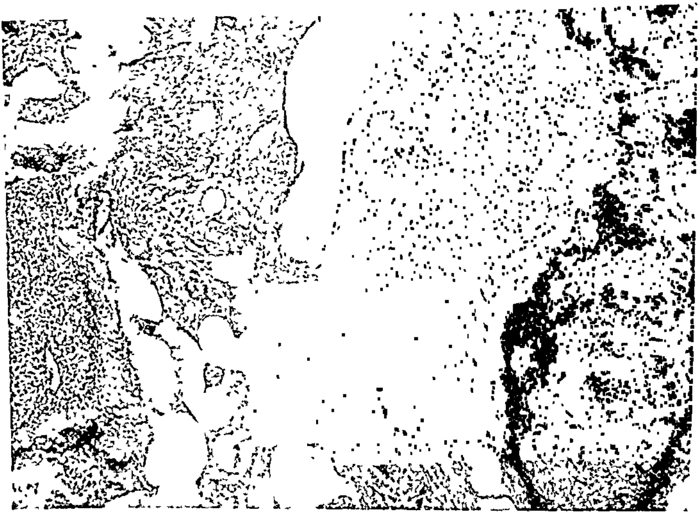

Fig. 5.—Photomicrograph from tumor showing transition zone. Note pleomorphism and irregularity of arrangement of cells. This chondrosarcomatous pattern was found principally between central well-differentiated and peripheral undifferentiated areas. (×100; reduced ¼.)

was not invaded. The mass was carefully separated from the vertebral bodies and their cartilages, to none of which was it adherent, and removed intact. Immediate inspection of the tumor and examination of its bed indicated its apparent complete removal and there was no gross involvement of bone. Convalescence was entirely uneventful, and the patient was discharged on the seventh postoperative day virtually free of pain. At this time, 14 months after operation, she is completely asymptomatic; physical examination is negative; spine and chest films are normal.

Pathologic Findings.—Specimen consisted of a firm, coarsely nodular mass measuring 9 by 6 by 6 cm. The greater portion of the tumor was encapsulated, but a crescentic rim on one surface was smooth and unencapsulated. The cut surface revealed a thick peripheral rim of firm pearly gray to pale yellow tissue and an irregular large central area composed of calcific and dense tissue (Fig. 2). Sections from the periphery of the tumor showed a very cellular and poorly differentiated sarcoma, the histogenesis of which was difficult to identify (Fig. 3). Large sections from the central area revealed an osteochondroma (Fig. 4); this was centrifugally succeeded by a chondrosarcomatous pattern (Fig. 5). This tumor in all probability consisted of an old osteochondroma in which the cartilage had undergone progressive transformation to malignancy as a chondrosarcoma and more recently to a highly undifferentiated sarcoma.

SUMMARY

A chondrosarcoma of the posterior mediastinum without demonstrable origin from bone, consisting of both benign osteochondromatous tissue and highly undifferentiated round cell sarcoma is presented.

Extirpation resulted in complete relief of severe unexplained thoracic pain of 2 years' duration, originally considered to be psychoneurotic in origin.

We are indebted to Dr. Lent Johnson and his staff of the Armed Forces Institute of Pathology, Washington, D. C., for thorough study and confirmation of the pathologic nature of the neoplasm.

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FACTORS INVOLVED IN THE RECOVERY OF A PATIENT AFTER PROLONGED VENTRICULAR FIBRILLATION DURING HYPOTHERMIA

Jorge B. Martinez, M.D., Irving Kass, M.D., and Murray S. Hoffman, M.D., Denver, Colo.*

VENTRICULAR fibrillation is still a formidable complication frequently observed during cardiac surgery performed under hypothermia. In spite of extensive investigation[1] little is known about either the etiology of ventricular fibrillation or the pathophysiologic mechanisms occurring during hypothermia. Because cooling causes almost all tissues to become less irritable, it is paradoxical that the heart becomes more irritable under the same circumstances.

The purpose of this report is to describe a case in which unusually prolonged ventricular fibrillation occurred during the closure of an interatrial septal defect under hypothermia, and in which there was a restoration of normal sinus rhythm only after the body temperature reached 32.5° C.

CASE REPORT

S. K., a 10-year-old white girl, was admitted to National Jewish Hospital on June 3, 1957. The third of four siblings, she was delivered at term after an uncomplicated pregnancy. During routine examination at the age of 18 months the patient was found to have a cardiac murmur. Development was normal, but the patient had been thin, underweight, easily fatigued, and had frequent respiratory illnesses. She became slightly cyanotic on excitement or overexertion.

Physical examination revealed no clubbing or edema, and there was no cyanosis at rest. Pulse rate was 88 per minute. Neck veins were not distended. The precordium was observed to be slightly overactive. The point of maximum impulse was in the fifth interspace at the midclavicular line. The size of the heart was slightly increased on percussion. A right ventricular thrust was felt along the left sternal border. A Grade 3, harsh, systolic murmur was heard along the left sternal border, loudest at the second left interspace. The murmur was well transmitted to the left shoulder. Though split during both inspiration and expiration, P_2 was of normal intensity. Blood pressure in both arms was 112/36 mm. Hg.

During fluoroscopy (Fig. 1) a marked increase in the pulmonary vascularity was observed. The right ventricle and the right atrium were enlarged. Main, right, and left pulmonary arteries were prominent and overly active. During a barium swallow, the left atrium appeared to be normal in size.

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The electrocardiogram (Fig. 2) revealed right ventricular hypertrophy with prominent R waves in right precordial leads and deep S waves in left precordial leads. The ventricular activation time in Lead V_{3R} measured 0.04 second.

Laboratory data: Urinalysis revealed the specific gravity to be 1.022, reaction 6, negative for sugar albumin and acetone, with 3 to 5 white blood cells per high power field on microscopic examination. Fasting blood sugar was 92 mg. per cent, blood urea nitrogen was 13 mg. per cent. Total protein was 7.3 Gm. per cent with albumin/globulin rate of 5.1 to 2.2. Alkaline phosphatase was 6.2 units, thymol turbidity 2 units, serum glutamic oxaloacetic transaminase 16 units. The cephalin flocculation test was negative at 24 and 48 hours. Bilirubin, 1 minute, was 0.15 mg. per cent. Hematocrit was 49 per cent; white blood count, 10,000 cells per cubic millimeter with a differential of 66 per cent neutrophils and 34 per cent lymphocytes. The red cell sedimentation rate was 10 mm. in 60 minutes.

On June 13, 1957, a right heart catheterization was performed. There was a significant elevation of the oxygen content of blood in the right atrium over blood in the superior vena cava. The elevation persisted throughout the right ventricle and pulmonary arteries. The right pulmonary artery saturation was 74.7 per cent. The oxygen saturation of blood in the brachial artery on exercise decreased to 79.6 per cent. At rest, the pulmonary artery pressure rose to 50/20 mm. Hg, whereas the right ventricular pressure rose to 77/-1 mm. Hg.

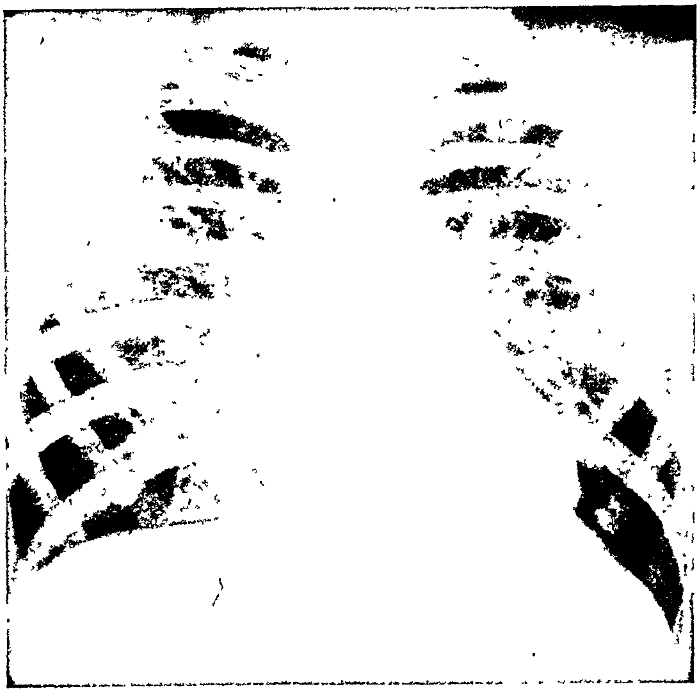

Fig. 1.—Roentgenogram, prior to surgery, showed prominent right atrium, main, right, and left pulmonary arteries, and increased lung vascularity. These are hallmarks of the secundum type atrial septal defect.

The resting systemic flow was 5,400 c.c. per minute, with a cardiac index of 4.7 L. per minute per square meter of body surface. The resting pulmonary flow was 6,600 c.c. per minute, with a cardiac index of 5.7 L. per minute per square meter of body surface. The pulmonary flow rose to 11,000 per minute and the index to 9.5 L. per minute per square meter following exercise. Total pulmonary resistances were 182 dynes per centimeter per second at rest and 189 dynes per centimeter per second on exercise. The superior vena cava oxygen saturation was 64.7 per cent and the saturation of the right atrium at different levels was 73.0 per cent and 74.0 per cent.

The catheterization data were consistent with a left-to-right shunt at the level of the right atrium. The gradient existing between the level of the pulmonary artery and the systolic level of the right ventricle was believed to be secondary to the high pulmonary flow.

On June 28, 1957, under induced hypothermia of 30° C, inflow outflow occlusion, procaine infiltration of the sino auricular node, and coronary arterial perfusion of oxygenated heparinized blood, a secundum type, 3 cm, interatrial septal defect was found and closed

While closing the incision in the right atrium, a tear developed. This began at the lower aspect of the interatrial fissure and extended to the inferior vena cava. There was a moderate blood loss and a delay in re establishing the temporarily occluded circulation. The time interval from total inflow outflow occlusion to release of the clamps was 9 minutes, 45 seconds The rectal temperature during the period of inflow outflow occlusion was approximately 30° C

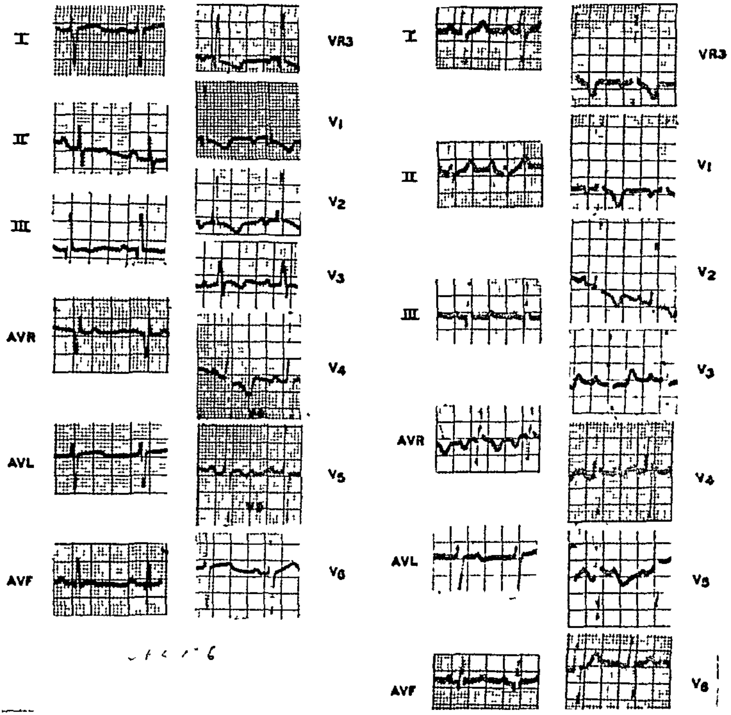

Fig 2 —Electrocardiograms before and after surgery The tracings reveal right ventricular outflow tract hypertrophy with no significant change after surgery

After the atrial bleeding had been controlled, the ventricles started to fibrillate (Fig. 3). This fibrillation resisted eight attempts at electrical defibrillation. On four occasions, 2 c c of Adrenalin (1:10,000) were injected into the pulmonary artery without response During this period the heart was bathed with warm saline solution which was poured into the chest cavity. Circulation was maintained for 60 minutes by intermittent cardiac compression. Care was used to squeeze the heart in the palm of the hand at [illegible] app mately 80 per minute. After 60 minutes, when the esophageal temper a transient normal sinus rhythm was observed. This was soon followed by atrial fibrillation. The aortic arch had been occluded for 1 hour and 18 minutes, during the period of ventricular fibrillation.

The chest was closed in layers, and the sternum was approximated with three interrupted sutures of No. 30 wire. A chest tube was inserted on each side posteriorly at the eighth interspace and a third on the right at the second interspace. At the time of closure of the incision, the patient's rectal temperature was 33.5° C. The patient had been given 1,000 c.c. of blood intravenously and 1,000 c.c. had been injected into the ascending aorta for coronary arterial perfusion.

During the first 36 postoperative hours, systemic hypotension was noted in the patient, who was then treated with Levophed, Neosynephrine, and blood. The urinary output during this time was only 300 c.c. The electrocardiogram 36 hours after surgery revealed an atrial flutter-fibrillation; the ventricular rate was 125 per minute.

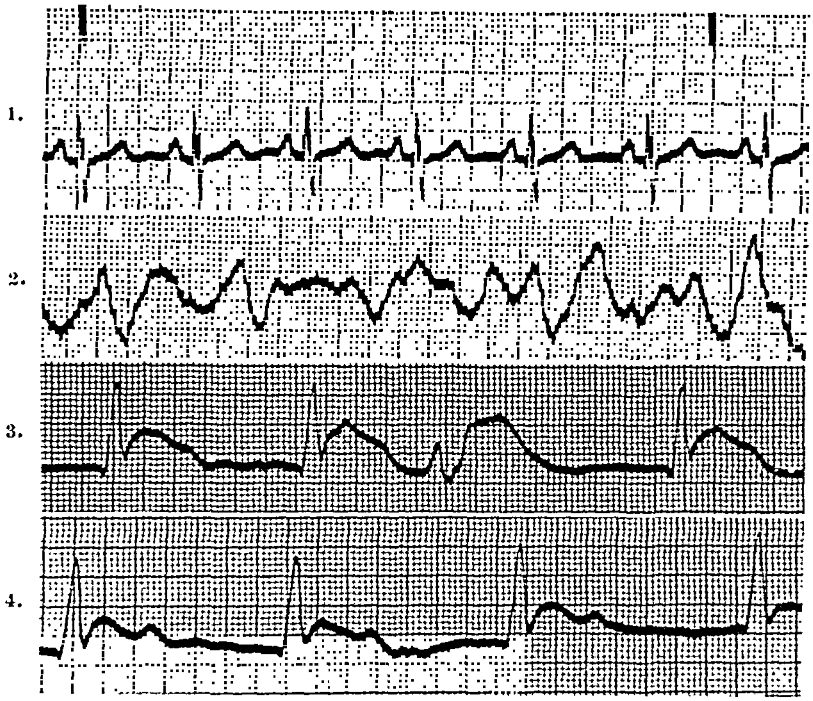

Fig. 3.—Lead II tracings taken during surgery revealed the development of ventricular fibrillation (2) and injury complexes following reversion to supraventricular rhythm (3 and 4).

On the third postoperative day, the urinary output increased to 1,200 c.c. Blood urea nitrogen was 34 mg. per cent. The rhythm was still atrial flutter-fibrillation. On the fourth postoperative day, the patient's general condition improved further. Urinary output was 1,400 c.c. Because the ventricular rate was rather high, 130 to 140 per minute, the patient was digitalized. On the seventh postoperative day, a regular sinus rhythm was established. At this time, the patient complained of tenderness of back and thigh muscles, and resisted straightening her legs. It was then observed that the deep tendon reflexes were absent in the legs and sluggish in the upper extremities. Abdominal reflexes could not be elicited. Her mental status was normal, and the results of neurological examination were otherwise within normal limits. Spinal fluid pressure was normal; only three lymphocytes were present per cubic centimeter; chloride was 118 mEq./L., protein 30 mg. per cent, glucose 58 mg. per cent, and serum glutamic oxaloacetic transaminase 13 units. It was believed that the patient had an injury to the anterior horn cells of the spinal cord. Complete muscle testing revealed weakness of scattered muscle groups in the back. Extensor and hamstring muscles of the legs were particularly tight. Straight leg raising was limited to 20 degrees.

An active program of muscle [illegible] was initiated and by July 29, 1957, she began to walk with the support of a [illegible]. [illegible] Aug. 18, 1957, hamstring spasm was minimal and muscle strength had increased. [illegible] 1957, 3 months after surgery, the patient had made satisfactory progress in [illegible] and showed good hip stabilization. Moderate muscle weakness persisted in the [illegible] group. The posterior tibial muscles were slightly weak, opposed by strong [illegible] resulting in eversion of the feet. Orthopedic shoes were used to correct this [illegible].

On Aug. 9, 1957, an electro[illegible] revealed widespread cortical irritability. The clinical implications of these findings [illegible]. The psycho[illegible] studies, which included Bender Gestalt, Draw-A-Person, [illegible] intelligence [illegible], disclosed that the patient had neither intellectual [illegible] nor any evidence [illegible] brain damage. She seemed to be functioning on a [illegible] in all her activities.

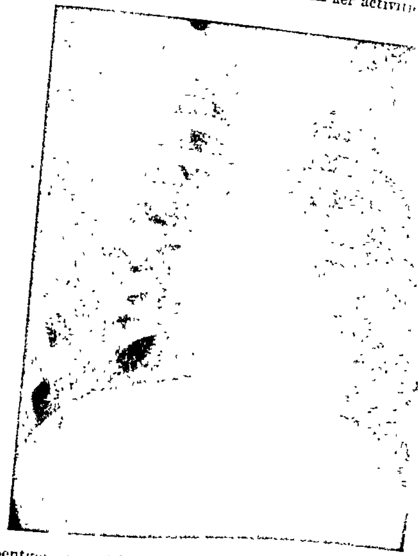

Fig. 4.—Roentgenogram taken [illegible] after surgery. The [illegible] than before surgery. Main, right [illegible] pulmonary arteries are smaller. [illegible] is smaller. Repeat catheterization [illegible] to be completely [illegible].

On Oct. 18, 1957, the patient was [illegible] significantly improved in [illegible] condition. Discharge examination on Oct. [illegible] revealed the pulse to be regular at [illegible] per minute. The precordium was quiet on inspection and palpation. No [illegible] or thrills were felt. A Grade 2, blowing, [illegible] murmur was audible at the second left intercostal space. P_2 was finely split [illegible] inspiration. The blood pressure was [illegible]/75 mm. Hg. Femoral pulses were normal. Neck veins were not distended. No edema or cyanosis was noted. Roentgenograms (Fig. 4) showed the [illegible] size of the heart to be definitely smaller. No [illegible] noted in the [illegible] of the [illegible]. Furthermore, the heart was significantly less [illegible].

Although there was slight residual [illegible] the [illegible] [illegible] that the required program of [illegible] the hospital.

DISCUSSION

Our observations in this case emphasize that ventricular fibrillation can last for an hour or more with subsequent complete recovery of the patient. Owens[2] described recovery following ventricular fibrillation which lasted 86 minutes during a normothermic operation. Husfeldt and Secher[3] have reported 3 cases of ventricular fibrillation lasting 114, 108, and 50 minutes during hypothermic surgery. (One case of interatrial septal defect and 2 cases of isolated pulmonic stenosis.) Complete recovery was observed in 2 cases and recovery with residual brain damage in the other.

The neurological changes observed in this case were undoubtedly the sequelae of spinal cord damage secondary to cross-clamping of the aorta for 78 minutes. At the present time, there is little information regarding the tolerance of the spinal cord to anoxia. Tolerance is greater in hypothermia, but the available data are equivocal, with estimates ranging from 30 minutes to 2 hours.[4, 5] In our case, the cross-clamping of the aorta was maintained in order to divert blood to the brain during the critical period of ventricular fibrillation and intermittent cardiac compression. The severe oliguria observed during the first 24 hours after surgery may have been a consequence either of the patient's shocklike state or of renal ischemia. It seems likely that the coronary and carotid perfusion with oxygenated blood during the period of total circulatory occlusion, followed by aortic occlusion during the period of ventricular fibrillation, were factors in preventing heart and brain damage.[6]

The extent of myocardial damage in this case was difficult to estimate. Transitory but reversible changes were observed in the electrocardiogram. Damage could have been a consequence of anoxia, or perhaps secondary to cardiac compression. It is known that there is a wide range of pathologic alterations in the heart following cardiac compression and that these changes may involve any or all of the cardiac tissues. The vascular structures within the myocardium and pericardium are most vulnerable, and usually there is a hemorrhagic extravasation of blood. Gross laceration and even perforation of the myocardium are not infrequent. It should be re-emphasized that the most important factor in avoiding such complications is the skill with which intermittent cardiac compression is performed.[1] Care must be exercised that one applies pressure with the palm of the hand instead of the fingers.

At present, the incidence of ventricular fibrillation is reasonably low during operations involving the atrial wall or pulmonary artery.[7] Cutting of the ventricle increases the incidence of ventricular fibrillation. However, as this case emphasizes, ventricular fibrillation can occur in cases in which the ventricles are not incised. When fibrillation does occur during hypothermia, its control is more difficult than during normothermia. There is general agreement that the temperature level should not drop below 28° to 30° C. Temperatures below this are attended by prohibitive incidence of ventricular fibrillation. Certain rather obvious, although at times forgotten, technical errors, such as an inaccurate thermometer should be studiously avoided. When fibrillation does occur, rewarming of the heart is usually necessary before electric shock will permanently revert the rhythm to one of supraventricular origin.

There is no uniform opinion concerning the rapidity of cooling. The rapidity varies according to the method used (surface cooling or extracorporeal technique) but in a medium sized adult a fall in temperature of 1° C each 6 to 8 minutes seems to be advisable and this approach was applied in this case.

It has been shown[8] that sino auricular blockage with Procaine is effective in preventing ventricular fibrillation in cooled dogs. This procedure was employed in our case. There are not enough data available to establish the validity of this procedure. Also, recommended, although not used in this case, is the administration of Prostigmin with coronary perfusion.[9] Because Prostigmin is a cholinesterase inhibitor, it is assumed that its antifibrillatory action is secondary to an accumulation of acetylcholine. A heart arrested by acetylcholine has been supposed to be less susceptible to subsequent hypothermic ventricular fibrillation.

Some authorities believe that infusions of dextrose, amino acids or fat intravenously, before and during hypothermia, reduce the incidence of fibrillation. It is not known whether these solutions act by alterations in the ion partition or by providing more nutrient to the heart. Dextrose was administered intravenously prior to surgery in this patient.

Careful electrocardiogram monitoring may be of value in detecting impending disaster. Loss of P waves, wandering pacemaker, slow rate, prolonged Q-T interval, and low voltage T waves are common and to be expected. However, marked prolongation of the QRS complexes with severe S-T segment depression herald ventricular fibrillation and demand immediate cessation of the hypothermia and warming of the patient. It is interesting that in this patient the ventricular fibrillation occurred suddenly without any electrocardiographic signs of warning.

SUMMARY

A case in which prolonged ventricular fibrillation occurred following the closure of a secundum type interatrial septal defect under hypothermia and coronary arterial perfusion is reported. The ventricular arrhythmia lasted 60 minutes, followed by recovery of the patient. Aortic occlusion above the left subclavian artery was maintained for 78 minutes in order to divert the blood flow to the brain and the heart. The only observed neurological sequelae in this case were attributed to spinal cord ischemia resulting from prolonged occlusion of the aorta. Coronary and carotid arterial perfusion combined with cross clamping of the aorta no doubt lessened the extent of brain and myocardial damage in this case. The ventricular fibrillation reverted to normal sinus rhythm after repeated electric shocks when the heart was warmed to 32.5° C. Such recovery after prolonged ventricular fibrillation should encourage surgeons to persist zealously in attempts to defibrillate.

The authors are indebted to George C. Heitzman, M.D., presently of Syracuse, N. Y., and Charles V. Demong, M.D., of Denver, Colo., who performed the surgery in the case. Goffredo Gensini, M.D., Chief of Cardiopulmonary Physiology at National Jewish Hospital, performed the catheterization of this patient. Baruch Bromberger-Barnea, Ph.D., Department of Research and Laboratories, kindly reviewed the manuscript of this report and offered many valuable suggestions.

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Erratum

In the September issue of the Journal, on page 325, Dr. Irving A Sarot's discussion of the three preceding papers was wrongly attributed to Dr. Irving A. Short. We regret exceedingly the misspelling of Dr. Sarot's name.

Announcements

THE AMERICAN ASSOCIATION FOR THORACIC SURGERY

Notice of Annual Meeting

The Thirty-ninth Annual Meeting of the American Association for Thoracic Surgery will be held April 21, 22, and 23, 1959, in Los Angeles, California. Headquarters will be the Hotel Statler.

Requests for Hotel Reservations

These should be mailed directly to Mr. William Truman, Reservation Manager, Hotel Statler, Los Angeles, California. Please mention this Association, the type of accommodation desired, the date, and approximate hour of arrival and departure. If accommodations are desired elsewhere in Los Angeles, please communicate directly with the hotel of your choice.

Material for the Program

SCIENTIFIC PAPERS.—Abstracts of all papers proposed for presentation at the 1959 meeting *must be received on or before November 15, 1958,* otherwise they will not be considered by the Program Committee. These should be labeled "For Thoracic Surgery Forum" or "For Regular Program" depending upon the nature of the subject matter, in the same manner as in previous years. They should contain from 200 to 250 words that accurately reflect the content of the completed paper.

Six, repeat, six clearly legible copies of *each* abstract must be sent to Miss Ada Hanvey, Administrative Assistant, The American Association for Thoracic Surgery, Suite 308, Carondelet Building, 7730 Carondelet Avenue, St. Louis 5, Missouri.

Essayists selected for the program are reminded that papers presented at the meeting *must* be handed to the secretary *immediately* after their presentation. If they are not ready at that time there is a chance that they will not be published in THE JOURNAL OF THORACIC SURGERY.

MOTION PICTURE SESSION.—Plans are again being made to show suitable motion pictures selected on a competitive basis. *The films themselves,* together with descriptive material concerning length of presentation, etc., must be received by Dr. John C. Jones, Suite 509, 1136 West Sixth Street, Los Angeles 17, California, *before November 15, 1958.*

Applications for Membership

Applications for Associate Membership in the Association must be received by the Membership Committee *not later than November 15, 1958,* otherwise the application will be deferred for consideration until the 1960 meeting.

Applicants must be sponsored by three Active or Senior Members of the Association. In addition to the signature on the application form, the sponsors will forward a *separate* letter concerning the applicant directly to:

Dr. Duane Carr
Chairman of the Membership Committee
899 Madison Avenue
Memphis 3, Tennessee

Sponsors are reminded that *new* letters of recommendation must be forwarded to the Chairman of the Membership Committee should their applicants be held over for reconsideration a *second year.*

The Journal of
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VOLUME 36
DECEMBER 1958
NUMBER 6

Original Communications

THE SURGICAL CORRECTION OF CALCIFIC AORTIC STENOSIS IN ADULTS

Results in the First 100 Consecutive Transaortic Valvuloplasties

Dwight E. Harken, M.D., Harrison Black, M.D., Warren J. Taylor, M.D. (by invitation), Wendell B. Thrower, M.D. (by invitation), and Harry S. Soroff, M.D. (by invitation), Boston, Mass.

INTRODUCTION

THE EVOLUTION of the surgical correction of aortic stenosis from the unlikely adventure of Tuffier[1] to the present day has been documented. We can refer to the work of only a few individuals who, with their associates, have contributed substantially. The *life cycle* of the disease has been studied by Levine,[2] Ellis,[3] White,[4] and Nadas.[5] *The pathologic patterns* have been reviewed in standard textbooks and by Edwards and McMillan. Techniques of surgical access have been improvised by Glenn[8] and Swann, W. K.[9, 10] The transventricular valvulotome operations have been tried widely and with varying success by Brock,[11] Bailey,[12] Glover,[13] Muller,[14] and Merendino.[15] Open operations under hypothermia have been used by Lewis,[16] Swan, H.,[17] and Morrow.[18] Other procedures using cardiac bypass have been described by Lillehei and Varco,[19] Cooley,[20] Clowes,[21] and Effler.[22] Closed transaortic

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From the Departments of Surgery of the Harvard Medical School at the Peter Bent Brigham Hospital and the Thoracic Service of the Mount Auburn Hospital.

This study was supported in part by Grant H-2419 of the National Heart Institute, United States Public Health Service.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

techniques with digital control have been advocated by Bailey,[23] Swann,[9] and by us.[21-26] Many are currently investigating prosthetic valve replacement as exemplified by the work of Sarnoff,[27] Hufnagel,[28] and Bush.[29]

What one cannot read in these discussions is the discouraging experience, largely unpublished, and available only through personal communications. This has led some cardiologists and surgeons to one of a variety of reactions: first, to conclude that the pathologic nature of aortic stenosis precludes a reasonable surgical attack until valve replacement is possible; second, that patients should be operated in an earlier phase of the disease or even before there is calcification of the cusps (this ignores the fact that many patients are not even known to have heart disease until after calcification occurs or that many patients with calcific aortic stenosis never become symptomatic); third, that surgeons should reject the patient in failure or those in the late phases of the life cycle of the disease. This interest in improving the statistical results of surgery is cold comfort to the physician already alarmed by a disease often suddenly fatal. He may be obliged to choose, with too little counsel, between the anonymity of the error of omission in "following" patients and the indictment of participating in commission should the patient die at surgery.

This complicated problem has been compounded by grouping all auscultatory evidence of obstructions in the aortic valve together, be they congenital, rheumatic or arteriosclerotic, calcific or noncalcific, young or old, compensated or in failure. In this kaleidoscope of variations in the disease clear definitions are needed in order to understand what facet is being discussed or treated.

PATHOLOGIC PATTERNS AND SURGICAL TECHNIQUES

In order to understand aortic stenosis the surgeon must study pathologic patterns and evaluate surgical techniques in the autopsy room. The "memory" provided by colored motion pictures is invaluable and in dramatic contrast to a study of formalinized specimens. We have extended this method by using the McMillan pulsator for observing normal and abnormal valves under lifelike hydraulic conditions. Furthermore, the pulsator affords an opportunity to practice various surgical techniques and to evaluate the degree of restoration. Such observations combined with our clinical experience with transventricular operations led us to abandon the blind valvulotome procedure in 1954.

While our dissatisfaction with the *transventricular operation* grew, it was observed in autopsy specimens that calcific aortic stenosis was often most effectively mobilized by digital maneuvers, not necessarily controlled by direct vision. This experience and that of Bailey[22, 23] and Swann[9, 10] led to the development of this transaortic operation. Conversely, when the valve was flexible, elastic and noncalcific, finger dissection was often unsatisfactory and manipulation under direct vision was helpful.

The standard pathologic patterns of calcific aortic stenosis are demonstrated in Fig. 1.

SELECTION OF THE PATIENT

The selection of the patients in this series for operation has been prev ously considered.[25, 26] The indications appear in Table I. In addition to th usual triad of angina, syncope, or left ventricular failure, auricular fibrillatio is considered an ominous finding because of the known rapid deterioration o patients with aortic stenosis once this inefficient rhythm becomes established The diagnosis of aortic stenosis is established by the presence of a diamond shaped aortic murmur, calcification of the aortic valve on fluoroscopy, an left ventricular hypertrophy by electrocardiogram. We consider frequent

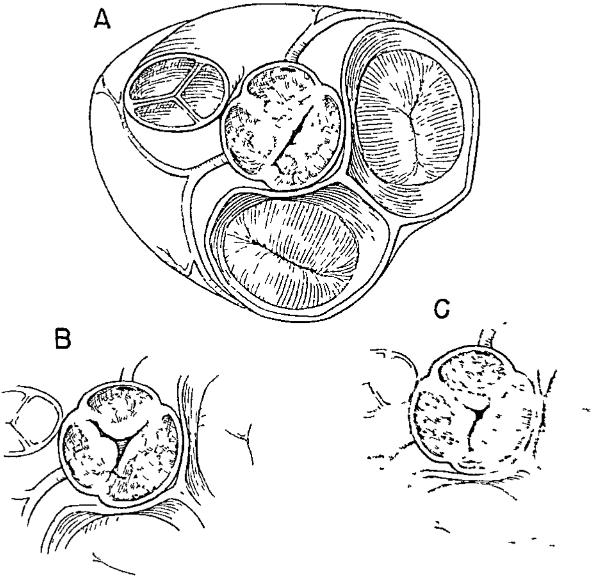

Fig. 1.—Common pathologic patt[illegible] occurs in approximately 40 per cent [illegible] Remainder are combinations of [illegible]

episodes of angina or [illegible] disease. Left ventricular [illegible] fibrillation, is an [illegible] presence of failure [illegible] a terminal pheno[illegible]

In a series [illegible] but who did [illegible] It is against [illegible] presented [illegible]

Age has not been a deterrent to operation, since 38 of these patients were between 51 and 66 years of age. The majority (72) were males in contrast to the findings in patients with mitral stenosis.

Calcification of the aortic valve was present in 70 of the 71 males and in 20 of the 29 females. The one male without calcification (No. 75, M. S.) was found at operation to have dominant mitral insufficiency. Aortic stenosis, although present, was minimal. Hence, this experience suggests that hemodynamically significant aortic stenosis in males rarely occurs in the absence of aortic valve calcification. Of the 9 women without calcification, only one (No. 81, G. D.) had isolated aortic disease. The remaining 8 had varying degrees of associated mitral disease.

We have not eliminated any patient because of advanced congestive failure. Others had manifested significant and progressive dyspnea (Table I).

TABLE I. TRANSAORTIC VALVULOPLASTIES (100 CASES)*

PREOPERATIVE STATUS	PERCENTAGE OF PATIENTS	OPERATIVE DEATHS	LATE DEATHS	UNIMPROVED	FOLLOW-UP LESS THAN 6 MONTHS	IMPROVEMENT			
						SLIGHTLY	MODERATE	MARKED	TOTAL
Dyspnea (1)—mild to moderately severe, little or no angina or syncope	37	2	1	2	15	1	6	10	17
Dyspnea (2)—moderate to severe angina but little or no syncope	22	5	3	1	0	0	3	10	13
Dyspnea (3)—usually severe with angina and syncope	5	1	0	0	3	0	0	1	1
Congestive heart failure—admission or recent past	24	7	5	3	3	1	4	1	6
Angina—little or no dyspnea or syncope	6	0	1	1	1	0	1	2	3
Syncope—little or no dyspnea or angina	6	1	2	0	0	0	2	1	3
Totals	100%	16	12	7	22	2	16	25	43

*Preoperative and postoperative clinical status following aortic valvuloplasty as determined by Dr. Laurence B. Ellis (supported by National Heart Institute, Grant H-142).

SELECTION OF THE OPERATION

The general clinical evaluation of these patients is discussed elsewhere.[25, 26] Ellis and co-workers[3] have given additional specificity through their retrospective study of the significance of angina, syncope, failure, and fibrillation. Their emphasis on the importance of failure, even in the form of dyspnea, and of the ominous significance of auricular fibrillation are important additions to the thinking in this field. Progressive dyspnea, in spite of medical treatment, has come to be recognized as an urgent warning that the patient is entering a late phase of the disease.

An important adjunct to the understanding of the pathologic patterns and varied clinical phases has been the observation of the patient at fluoroscopy. By this technique it is possible to make some estimate of left ventricular size and activity, of aortic arch size and activity, and thereby a differentiation between stenosis and regurgitation. Calcification is best identified by this technique and usually a differentiation of bicuspid, tricuspid, or punctate forms can be established, as well as the mobility of specific cusps. The increasing availability of image intensifiers should increase the importance of this preoperative assessment.

In the absence of a suitable prosthesis for valve replacement a choice must be made on the basis of available experience and autopsy examination of the best alternative operation for various types of aortic stenosis. We have not had the personal experience with noncalcific congenital aortic stenosis in children which would permit the selection of the optimal technique. Transventricular dilatation, however, would not seem to be definitive, and the aorta is too small for the application of an operating tunnel and for digital manipulation. Here, just as in congenital pulmonic stenosis, direct vision valvuloplasty seems logical. The size of the aorta and texture of the valve both favor open operation.

Our strong preference for the transaortic operation for aortic stenosis is based on the unsatisfactory results that followed our initial efforts with the transventricular approach. Of 23 patients operated on by this route 10 or 43 per cent were listed as operative mortalities and 10 have subsequently died. The concept that "selective insufficiency" could be borne by the hypertrophied left ventricle is now known to be erroneous. In 9 recent patients with combined aortic and mitral stenosis, we were lured back to the simpler transventricular procedure combined with mitral valvuloplasty by the availability of improved aortic dilators, the encouraging reports of Brock, Glover, and Muller, and the limitations of the transaortic operation. The procedure, although simple to perform, has again produced discouraging results. There were four operative deaths and one late death. The inability to assess directly what is being done to the valve renders this a poor approach. It is also probable that operative aortic regurgitation is more likely to occur. This small additional experience further substantiates our conviction that the transaortic route is vastly superior and we now find little place for transventricular procedures.

Following these unsatisfactory experiences, we turned to the transaortic approach with the important addition of an operating tunnel of Ivalon* designed by Dr. Hugh E. Wilson, a former associate. This series consists of 100 adult patients with severe aortic stenosis, heavily calcified in 90. These patients suffered various degrees of congestive failure (Table I). It is hoped that a comparison of the results of this study with that of others employing other techniques in similar patients will indicate the most reliable procedure.

In dealing with combined mitral and aortic stenosis, the sternal splitting incision allows adequate approach to both valves. Nineteen patients in the present series have had the mitral valve explored at transaortic valvuloplasty. In 14, significant stenosis was corrected in this valve as well. The overall operative mortality rate for this combined operation compares favorably with that for the aortic procedure alone (10.5 and 17.3 per cent respectively). It is interesting to note that combined aortic and mitral stenosis was present in 53.5 per cent of the women in this series as contrasted with only 9.7 per cent of the men.

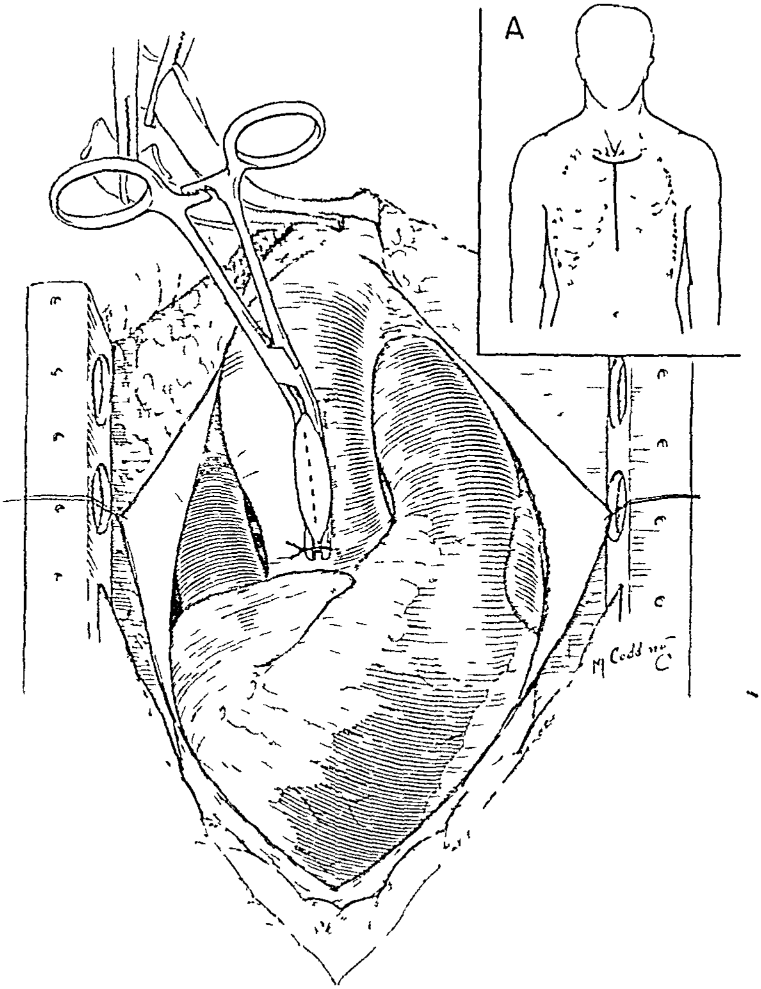

Fig. 2.—Technique of transaortic valvuloplasty—incision and exposure. *Insert*—Mid-line sternotomy. Curved Atraugrip clamp excludes a segment of ascending aorta Rubber dam drains about right innominate and left common carotid arteries.

OPERATIVE TECHNIQUE

The operation employed is a transaortic digital manipulation of the valve employing an Ivalon sponge operating tunnel, as described and illustrated in detail elsewhere.[26]

The sternal splitting incision is important. It is well tolerated by seriously ill patients since they are operated upon in the dorsal decubitus position, allowing the pleural spaces to remain intact with both lungs available for ventilation

(Fig. 2). In addition, the placement of the aortotomy site on the anterior and most accessible portion of the ascending aorta permits support of the suture line by the reapproximated sternum. In none of these was a postoperative aneurysm observed, in sharp contrast to the 2 in whom a right lateral approach was used. One of the latter died from an aneurysm at the aortotomy site, and, in the other, limited exposure resulted in an unsatisfactory manipulation.

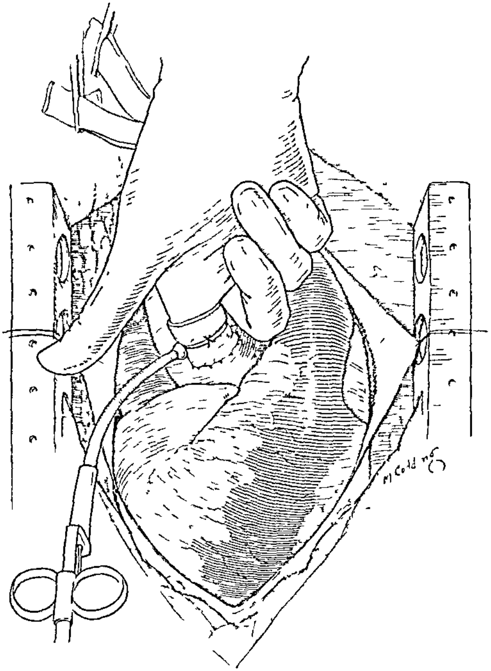

Fig. 3.—Technique of transaortic valvuloplasty. Ivalon tunnel sutured to aortotomy. Operator's finger in aorta above valve.

The Ivalon tunnel is an essential feature of this operation. In the first 28 procedures, the operative as well as late results were unfavorably influenced by the use of other materials in making the tunnels (Fig. 3). Rubber, pericardial, plastic, and cloth tunnels seem much less attractive. The sponge tunnel can be sewed in place easily and with excellent hemostasis. The maneuvers need not be hurried, as they invariably are when an alarming amount of blood loss occurs at the tunnel anastomosis. The patient's blood pressure and coronary perfusion can recover between manipulations. In this series, intra-aortic manipulation has varied from 10 to 45 minutes. There are conspicuous limitations to any technique that attempts to convert these calcific masses into effective flutter valves with maximal reduction of resistance to forward flow and minimal production of regurgitation. The ability to assess deliberately leaflet activation by the ventricle is a striking advantage of this technique over transventricular and open operations. Another advantage of this tunnel exploration is the facility with which the stenotic orifice may be located. In the extensively calcific valve of punctate form there may be considerable difficulty in locating the orifice under direct vision when there is little flow. The visibility is only relative and any pit containing blood looks like an orifice. Contrariwise, palpation of the jet issuing from the orifice during tunnel exploration permits prompt location.

More effective mobilization of leaflets has been possible since we have learned to insinuate the fingernail, then the bare finger under the broadest zone of fusion at a hinge zone. The finger can then find the opposing fused commissure and fracture from the smooth underside by lifting upward.

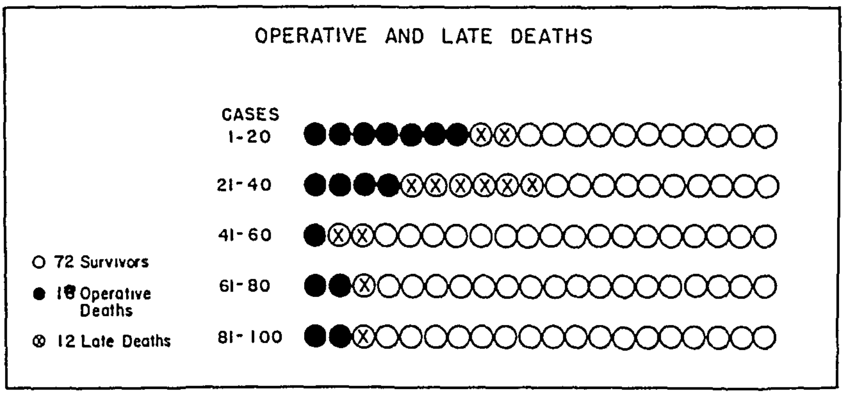

Fig. 4.—Operative and late deaths. Note reduction of operative mortality to 5 patients in last 60.

Once a fracture has started, gentle manipulation widens and stretches the commissure at the annulus until maximal mobilization of the cusps has been provided. Palpation will reveal the degree of mobilization that the left ventricle can effect in the cusps. It may be of no value to force the finger through an orifice and then assume that the effective valve area has become finger size. The ventricle may be totally incapable of producing a similar orifice. With mobilization, the leaflets may close more effectively as well as open more readily, thus reducing regurgitation as well as stenosis. Overcorrection, the *bête noire* of the field, seems more of a hazard in open surgery.

This closed technique also permits accurate timing of head vessel occlusion to prevent embolization. The first operation in this series resulted in the death of the patient from multiple calcific emboli. Head vessel occlusion for 10 to 20 seconds after each manipulation, when particles might be dislodged, has eliminated the problem of embolization.

OPERATIVE DEATHS

There were 16 deaths in this series of 100 transaortic operations. The operative mortality in the early portion of the series was high (7 of the first 20) (Fig. 4). In the last 60 patients there have been but 5 deaths (8 per cent).

Operative mortality figures afford only the crudest basis for judging a procedure but the current mortality rate of 8 per cent compares most favorably with that of the open procedures. There has been no significant difference in the operative mortality rates between the two sexes.

Four deaths were due to the production of aortic insufficiency. Two others occurred in patients with preoperative aortic insufficiency and severe congestive failure. Technical faults were responsible for three deaths (calcific emboli, postoperative hemorrhage, and tear of the base of the aorta). One other patient died on the table from cardiac arrest.

Acute arrhythmias leading to ventricular fibrillation at 12 hours, 24 hours, and 3 weeks after operation occurred in 3 additional patients. The remaining 3 deaths were not directly related to the surgical procedure (aspiration of vomitus, liver failure secondary to congestive failure, and hemorrhage from a peptic ulcer) but they do reflect the advanced nature of the disease.

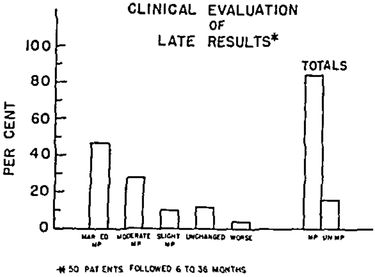

Fig. 5.—Percentage of improvement following operation in 50 patients followed more than 6 months.

FOLLOW UP STATUS

Among the 100 patients in this series, 84 survived the operation. Late death has occurred in 12 from 1 to 31 months after surgery (average 11.9 months). Congestive heart failure was the predominant cause in 6 of these, probably due to inadequate relief of the stenosis. In 2 others the congestive heart failure was associated with aortic insufficiency. The remaining deaths were attributed to an infected aneurysm at the aortotomy site, arrhythmia, subacute bacterial endocarditis in a patient who refused to take prophylactic penicillin, and a fresh myocardial infarction in a patient who had had his initial infarction 1 year before surgery.

Of the 72 survivors, 50 have been followed 6 months or more and 43 or 86 per cent of these are improved (Fig. 5). The majority are asymptomatic and working. These patients are being reassessed at 6 month intervals by Ellis and will be reported independently. At the time of publication the status according to clinical groups is shown in Table I. It will be seen that 88 per cent of these patients had been in overt congestive failure or had manifested dyspnea before operation.

The percentage of improvement is quite similar in all groups except those who had been in recent overt congestive failure, but even among these there was significant salvage.

HEMODYNAMIC STUDIES

Clinical follow-up studies following any operation are of primary importance, since the objective is the relief of symptoms and prolongation of life. All survivors are being followed clinically. In addition, objective hemodynamic studies before and after operation add greatly to our understanding of the procedure. We have been able to study 22 patients in this series by left heart catheterization both before and after transaortic valvuloplasty.*

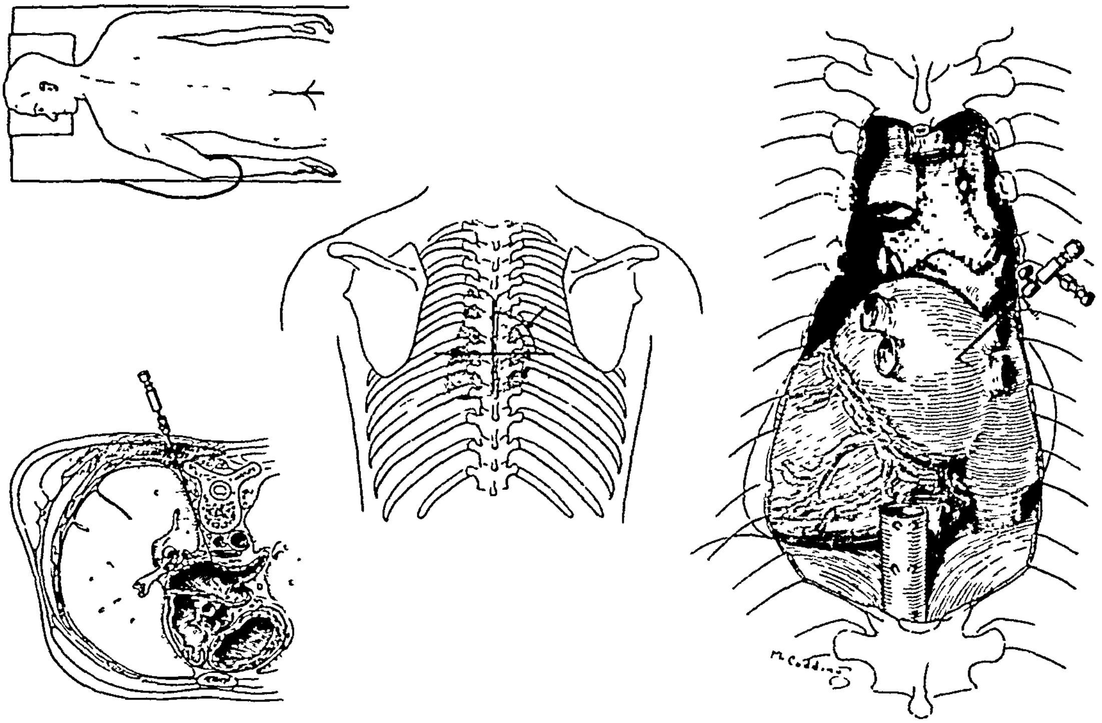

Fig. 6.—Technique of percutaneous left heart catheterization.

The technique employed in left heart catheterization has been derived from that of Fisher,[31] inserting a No. 16 thin-walled needle percutaneously into the left auricle under fluoroscopic control (Fig. 6). Through this a polyethylene catheter (PE 60) is inserted and pressures recorded in left auricle, left ventricle, and brachial artery. Cardiac output was determined by indicator dilution curves sampled at the brachial artery following left auricular injection. These curves have also been analyzed by a modification of the Korner-Shillingford formula for regurgitation and, in each case, a decision made on clinical grounds whether to consider the regurgitation to be located in the mitral or aortic area. When significant aortic insufficiency was present the calculations of aortic valve area and left ventricular work have included a correction for this factor. It is recognized that the assumptions involved in the use of indicator dilution curves for the determination of regurgitation are open to some question, but at the moment they are the only method available. Nevertheless, our experience in evaluating pure mitral valvular disease would indicate that the method is usually reliable.

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*We are indebted to Dr. Lewis Dexter, Dr. Richard Gorlin, and Dr. Walter H. Abelmann under whose auspices these catheterizations have been performed.

In the first 75 patients in the series the studies were limited primarily to diagnostic problems. When it became apparent that good clinical results were being experienced in patients in whom the catheterization data appeared less dramatic, we elected to catheterize all possible patients in the last 25 of the 100. These consecutive studies should provide accurate evaluation of the quality of our current surgery. Only 11 of the last 25 patients were studied because of other obligations in the laboratory, administrative problems, and the fact that some patients had had adequate studies elsewhere prior to reference to us. This latter series was operated on at a time when the lessons learned earlier could be applied, therefore these patients probably had a more effective operation. This can be detected in the last 11 patients represented in Figs. 7, 8, and 9.

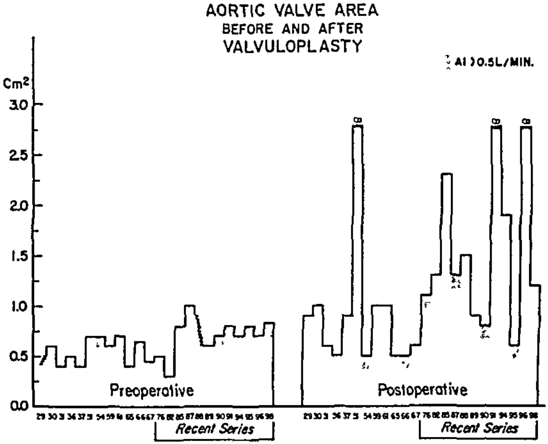

Fig. 7.—Aortic valve area calculated by Gorlin formula before and after operation.

Aortic Valve Area.—The valve area was calculated according to the hydraulic formula of Gorlin,[32] taking into account the degree of aortic regurgitation as indicated above. All but one were below 0.8 cm.^{2} preoperatively (Fig. 7). Those with significant regurgitation are indicated by shading, since this factor produces a critical hemodynamic situation at a larger valve area than is true when stenosis exists alone. Gorlin has estimated that dynamically significant stenosis occurs at about 0.5 cm.^{2} with pure aortic stenosis, and as high as 1.5 cm.^{2} if associated with significant regurgitation (Fig. 10).

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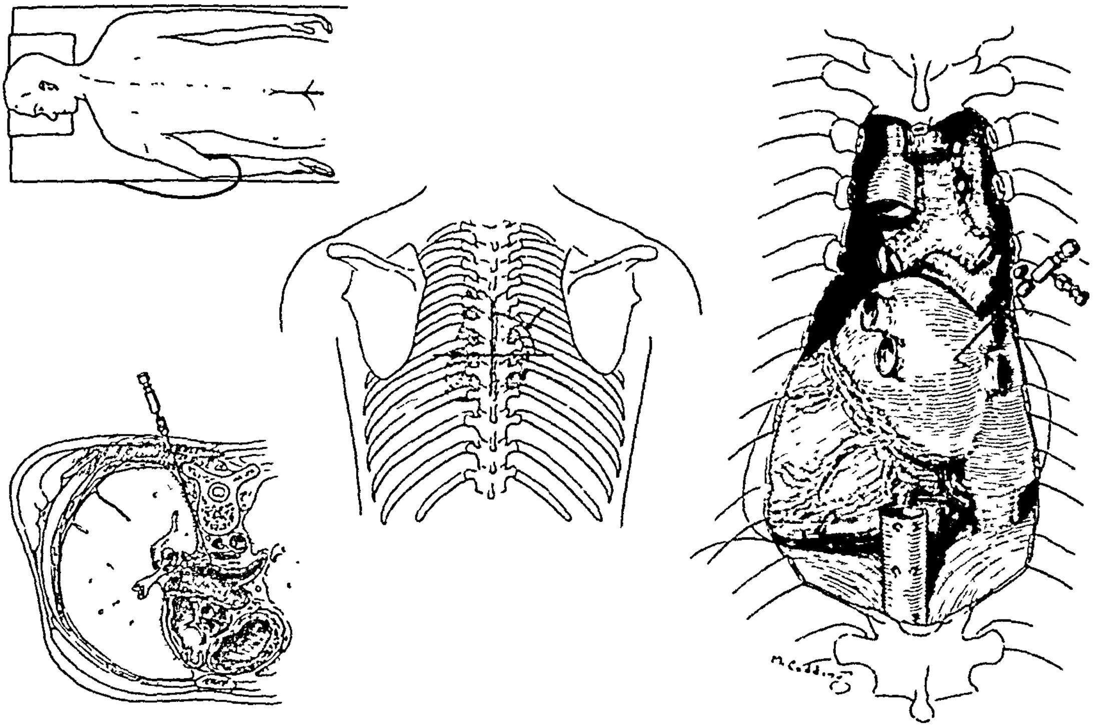

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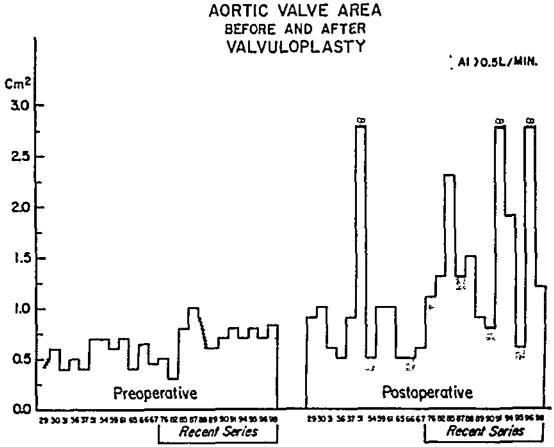

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Postoperatively, all but 8 of the patients had valves calculated to be 0.8 cm.^{2} or more and 13 were 1.0 cm.^{2} or larger. In 3 cases, the aortic gradient was entirely eliminated indicating an effective valve area of 3.0 cm.^{2} or greater.

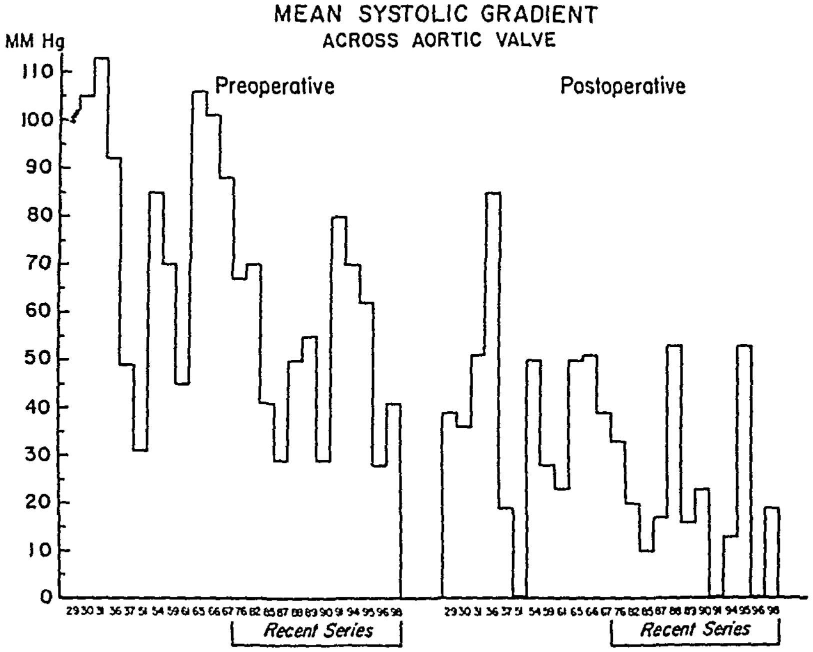

Fig. 8.—Mean systolic pressure gradient across aortic valve before and after operation.

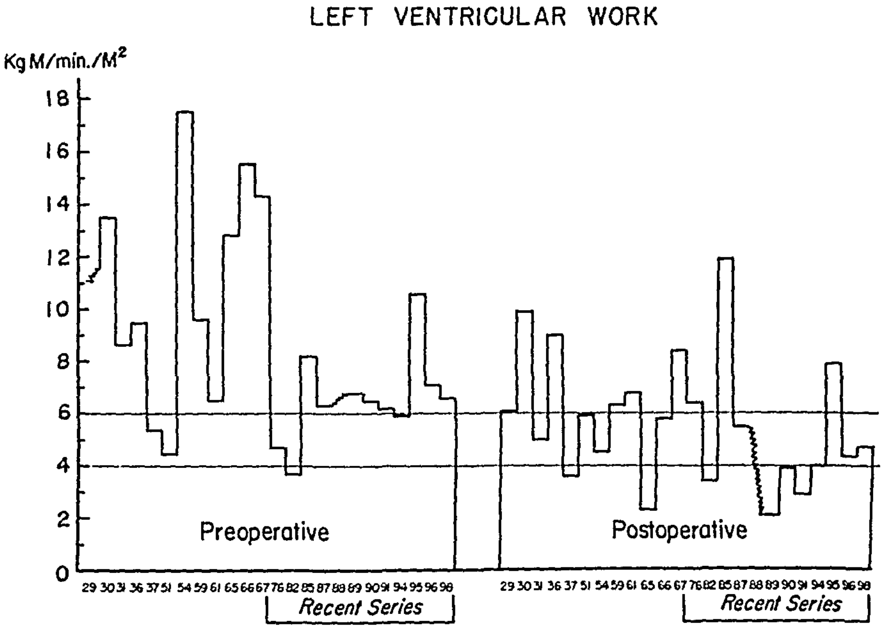

Fig. 9.—Left ventricular work before and after operation. Shaded bars indicate presence of aortic insufficiency in excess of 0.5 liters per minute.

Aortic Valve Gradient.—The preoperative mean systolic gradient across the aortic valve was greater than 40 mm. Hg in all but 4 of the patients studied and ranged as high as 113. This gradient fell postoperatively in every case but

1. In 10 patients it was reduced below 20 mm. Hg, a level now considered to be of little hemodynamic significance. The aortic valve gradient per se, without concomitant flow studies, is of limited value. Gradients in patients with low flow in failure are deceiving. This accounts for the low values recorded here (Fig. 8).

Left Ventricular Work.—Although the computed figures for valve area postoperatively were somewhat disappointing in some cases, this finding has not by any means precluded a satisfactory clinical result. The work performed by the left ventricle is perhaps of greater significance. A reduction of this factor below the critical level may reflect more accurately the relief of symptoms than does the absolute valve size. After operation, 16 of the 23 patients studied had the work of the left ventricle reduced to 6 Kg. M./min./$M.^2$ or below, a level considered to be within normal range (Fig. 9).

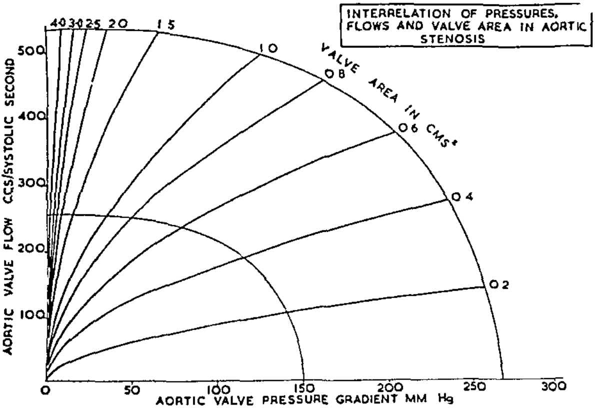

Fig. 10.—Diagram showing relation of pressure to flow for any given degree of aortic stenosis. Note minimal increment in flow despite marked increase in gradient in valves of 0.5 cm.² area or less. (Gorlin et al.: Am. J. Med 18: 855-870, 1955.)

DISCUSSION

A review of this series of 100 patients who have had a transaortic valvuloplasty for the relief of aortic stenosis emphasizes several points. It is clear that the symptomatic patient with aortic valvular obstruction has a disease that is often fatal within a matter of months as documented by our control series. As Wood[31] has pointed out, the prognosis for relief or survival on medical therapy alone is poor. The operation presented, although not curative in the majority, has offered good palliation to many at an acceptable operative risk. We cannot agree with those who urge early operation "before calcification occurs" simply to minimize the technical problems. Nevertheless the development of symptoms in a patient with the murmur of stenosis should warn the physician of impending rapid deterioration and prompt consideration of surgical relief is in order. Left heart catheterization may clarify the problem.

At the other end of the spectrum is the patient in congestive heart failure who should not be denied operation simply because of increased operative risk. He has a malignant disease on medical treatment yet surgery may offer some salvage.

When hemodynamic evaluation can in some instances show so little change yet the clinical improvement be great, or vice versa, we realize that even these techniques leave something to be desired. Gorlin[30] has recently been studying coronary flow in these patients. Patients with aortic stenosis show a fixed coronary flow at rest, on exercise and with nitroglycerine. Presumably, the excessive ventricular work calls for maximal coronary dilatation. It will be significant if further studies show that the fixed coronary flow of advanced aortic stenosis can become variable after surgical correction. Such a study might help us in the selection of patients for operation and also facilitate the evaluation of results.

SUMMARY

1. One hundred patients with symptomatic aortic stenosis have had surgical correction by a transaortic procedure. There have been five operative deaths in the last 60 patients (8 per cent). Twelve late deaths have occurred in the entire series.
2. Clinical appraisal of the survivors, followed from 6 to 36 months, indicates that 86 per cent are improved.
3. Hemodynamic evaluation by left heart catheterization before and after operation shows that the valve area is significantly increased, the mean systolic gradient reduced, and that the left ventricular work falls.
4. Serious consideration for surgical relief is advised in all patients with symptomatic aortic stenosis.
5. A plea is made for careful preoperative and postoperative clinical and hemodynamic evaluation of patients with aortic obstruction. This should facilitate the proper choice of closed or open operation in the various patterns of disease.

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34 Fisher, D L The Use of Pressure Recordings Obtained at Transthoracic Left Heart Catheterization in the Diagnosis of *Valvular Heart Disease*, J THORACIC SURG 30 379, 1955

DISCUSSION

DR ELMER P R MAURER, Cincinnati, Ohio—I would like to emphasize the importance of an observation made by Dr Harken that has to do with the preoperative evaluation and determination of the etiological background in choosing the method of surgical approach for aortic stenosis The results obtained will depend in great part on this determination In aortic stenosis resulting from rheumatic fever, one would anticipate commissural fusion characteristic of this disease and the transaortic approach might very well be anticipated to give good results In the arteriosclerotic, calcified form of aortic stenosis, no commissural fusion will be anticipated and I think the percentage of good results will be decreased (slide) With either the open or closed approach, it is hopeless to expect good results in those situations where one has complete replacement of the aortic valve by a calcified block. Taking into consideration all aspects of the problem, including the added risk of open aortotomy with electric cardioplegia or retrograde coronary perfusion with extracorporeal circulation, we have preferred to use a transsternal plastic tunnel closed approach in those individuals who have a definite rheumatic history and the classical commissural fusion.

(slide) The valve is approached through the tunnel and commissurotomy is completed by finger fracture or cutting technique.

(slide) This shows the aorta closed.

We have encountered no problems in postoperative hemorrhage utilizing this approach.

We certainly believe that open approaches are mandatory in all instances of congenital aortic stenosis. I doubt very much whether any approach is satisfactory in those instances where the aortic ring and valve is completely replaced by calcium. Perhaps in the future we may find ourselves exploring the aortic valve by one of the closed techniques, being prepared to proceed with the open operation if it seems impossible to do it by the closed approach.

In summary, we have preferred transaortic commissurotomy, utilizing the plastic tunnel developed by Dr. William K. Swann, in those instances where a definite history of rheumatic fever is established, the stenosis is of short duration, and no calcium is seen on fluoroscopic examination of the aortic valve. All other stenotic aortic valve lesions are operated on by the open approach.

DR. ROBERT P. GLOVER, Philadelphia, Pa.—Dr. Harken has presented his subject in his usual masterful way. Whereas we agree wholeheartedly that, at the present moment, closed methods for the surgical treatment of acquired aortic stenosis are preferable, it is our feeling that the transventricular route to the aortic valve is simpler, faster, and safer than the aortic approach and will yield a more satisfactory functional clinical result in a greater number of patients.

(slide) From 1951 to the present we have used transventricular commissurotomy for aortic stenosis in 87 consecutive cases. During this period, twice this number have either refused surgery or have been turned down and each of these has long since died. There has been no inclination to employ other techniques, for acquired calcific stenosis presents a derangement in anatomy and pathology incompatible with definitive, restorative reconstruction in the ordinary sense of the term. In the majority of such cases, the valve is indurated and calcified to the point of complete replacement and distortion of normal valvular tissues. It is an immobile "concrete dam." Under these circumstances and short of *total resection* of this scar with suitable prosthetic replacement, there is no advantage to employ techniques (complicated, tedious, time-consuming, and of considerable risk) which provide for either direct palpation or visualization of the valve. To be sure, ultimately open surgery with valvular replacement will be the effective treatment, but until such a valve replacement becomes available it must be recognized that safe and effective palliation is all that can be offered. This can best be accomplished through the left ventricle.

Originally, most surgeons used the transventricular approach with uniformly poor results. Large, bulky dilators requiring constricting purse-string sutures on the left ventricular myocardium resulted in stellate lacerations of this muscle with its attendant hemorrhage and arrhythmias and were responsible for the high mortality. Our first 37 consecutive cases were no exception for, within the first month of surgery, the mortality was 46 per cent, obviously intolerable. To be sure, these deaths were in patients already in advanced left ventricular failure, and poor risks. Surprisingly, however, 11 or 30 per cent of this group are still living and improved 3 to 7 years after surgery, indicating that, when tolerated, split-dilatation of these valves provides reasonable palliation.

(slide) Results such as these indicated the left ventricular approach in the minds of most, hence the search for and employment of other methods. Our technique through the left ventricle was changed. By using the Brock two bladed dilator (no larger than a lead pencil) small, one centimeter incisions in the myocardium only were necessary and no purse-string or stay sutures were needed. Manipulation and trauma to the left ventricle have been minimal and blood loss rarely exceeds 2 to 3 ounces. The improvement in results has been dramatic. Since 1951, in 50 consecutive cases, there has been an operative mortality of 6 per cent (3 cases). Of the surviving patients, 70 per cent have been greatly improved and are remaining so (1 to 3 years). Aortic insufficiency with diastolic levels below 30 mm Hg has occurred in only 3 patients. There have been no embolic phenomena in any of the patients receiving aortic commissurotomy alone ([illegible] were fatal emboli with one death occurred in combined aortic and mitral commissurotomies of which there were 21 in the 57 cases. Pressure gradients across the aortic valve taken in all 50 cases, pre- and postcom[illegible] at the time of surgery, have resulted in a drop from an average of 78 [illegible] Hg [illegible] mm Hg. This hemodynamic improvement, while not perfect, can hardly be [illegible] when one remembers the pathology present the mere presence of which will [illegible] its immobility provide some obstruction to left ventricular outflow whether [illegible] are open or not.

Thus, we are [illegible] The [illegible] is not in the approach through the left ventricle but in the tool [illegible] results will be obtained only when patients with this disease are [illegible] earlier in their pathologic course or when these diseased valves (the [illegible] called valves) can be totally resected and replaced by [illegible] from the practical standpoint, palliative surgical treatment [illegible] the patient his best opportunity for an improved clinical state.

DR. WILLIAM W[illegible] Dr. Harken and his colleagues have reported a [illegible] valvular lesion. We have had [illegible] protracted interest in the [illegible] to the functioning aortic valve. [illegible] experience with this technique [illegible] such as Dr Harken's large series, is of the [illegible] importance in the successful relief of calcific aortic stenosis. In a smaller series, [illegible] on two occasions produced uncontrollable aortic regurgitation by the combined [illegible] and instrumental dilatation of the aortic valve in the functioning heart and we [illegible] that, in both instances, it was due to avulsion of one aortic cusp from its point [illegible] attachment to the wall of the aorta. Further, it has never been possible for us to open [illegible] than two commissures by this method and frequently it has been possible to open [illegible] commissure.

Despite our continued interest in the direct [illegible] to the pulmonary valve [illegible] the mitral valve, we have come [illegible] to us and per[illegible] for some [illegible] of lesser experience than Dr Har[illegible] approach [illegible] the aortic stenosis should [illegible] condition demands that something [illegible] logy. One should [illegible] mind, how[illegible], such as a predom[illegible] might obtain with open [illegible] on a patient with calcific [illegible] The [illegible] lost nearly 60 pounds of [illegible] of two commissures was obtained [illegible] However, [illegible] commissure could not be open[illegible] the valve survived operation and was app[illegible] months, when he [illegible] died. The slide shows the [illegible] of the valve despite separation of the commis[illegible] result in calcific aortic [illegible] may be determined by several [illegible] immobility of the valve [illegible], refusion of the commissures [illegible] where the leaflets are [illegible] calcified; and finally, the limit[illegible]

DR. CHARLES P. BAILEY, Philadelphia, Pa.—I have enjoyed Dr. Harken's paper very much and am glad that he emphasized the commissure. However, a heavy responsibility rests upon me; first, for originally promulgating the closed approach to the stenotic aortic valve and, second, for failing to recognize the necessity for bringing about flexibility of the surgically separated valve segments. Today it seems to me that it is wrong to continue these closed techniques for the reasons Dr. Scannell showed so well yesterday. The valve structure is not simple and there is much more advantage in operating by an open technique than is the case with the mitral valve. We feel that, while many patients are clinically benefited by the closed procedures, it is only because a relatively slight enlargement of the orifice beyond the critical size brings about a rather great clinical improvement. Postoperative physiologic studies by Goldberg and others have shown that we do not accomplish much opening of the stenotic valve by any closed method. It is not surprising that many of our surviving patients are beginning to show evidences of recurrence of the stenosis and will require further (more adequate) intervention in the future. For this reason, 86 cases ago we decided to do only open operations for aortic stenosis. When we look at the valve it is not the same as feeling it digitally or palpating it instrumentally.

(slide) This is a valve which may be considered as typical or reasonably representative of these cases, although I know that there are very many variations. Note that the calcification is limited to the concave or "spongiosa" layer of the cusp. The convex or "fibrosa" layer would be relatively thin and flexible if it were dissected away from the former. By a painstaking technique, somewhat analogous to soap sculpture, it is possible to remove the extremely scarred and calcified spongiosa layer. By this means not only is a great deal of flexibility imparted to the mobilized valve cusps, but also a significant degree of ''lengthening'' of the cusp is produced which renders the valve more competent.

DR. DWIGHT E. HARKEN (Closing).—Thank you, gentlemen, for your discussion and your nice comments. Thank you, Dr. Bailey, for your reference to the removal of calcium as "sculpturing" reconstruction. We have been unable to remove the calcium without producing hopeless defects. Furthermore, we can assess what the ventricle can do for valve motion better with the finger during the closed operation.

Dr. Glover and Dr. Maurer have accepted my basic reasoning. I'm not quite sure that I can entirely return the compliment, for the limitations of the transventricular technique seem virtually prohibitive to us. With Dr. Glenn's position I agree, however, that the technical advantages of a properly used Ivalon tunnel seem substantial. Dr. William Glenn has been a pioneer in the use of operating tunnels for intracardiac surgery.

In closing, I cannot possibly comment adequately on all the excellent points made by the discussers. It must suffice to say that we have patients in a symptomatic phase of a highly lethal disease. We recognize certain variations in the pathologic process. It seems to us that open operation has advantages in noncalcific aortic stenosis. Open operation certainly has a preferred place in subaortic stenosis in children. Conversely, heavily calcified stenosis in adults (with adequately large aortas) has been handled in a fairly but not perfectly satisfactory manner by this Ivalon operating tunnel in a transaortic retrograde fashion.

We need to pool and compare our results when operating on similar pathologic patterns in similar phases of the life cycle of this disease in order to adopt the most appropriate operations and to make the best recommendations to others. This evaluation must include operative and late mortality, pre- and postoperative clinical evaluation and, imperfect as it is, the most exhaustive, objective hemodynamic studies before and after our intervention. Only in this way can we work responsibly until the "perfect" operations are available.

Again, thank you.

SURGICAL TREATMENT OF THIRTY-FIVE CASES OF DRAINAGE OF PULMONARY VEINS TO THE RIGHT SIDE OF THE HEART

Henry T. Bahnson, M.D., Frank C. Spencer, M.D. (by invitation), and Catherine A. Neill, M.D. (by invitation), Baltimore, Md.*

Since the development of methods for accurate diagnosis of cardiac defects anomalies of the pulmonary venous return have been reported with considerable frequency. Partial anomalies of the pulmonary veins have been often encountered in the repair of atrial septal defects and various methods have been described for closing the defect and concomitantly correcting the anomalous venous return.[5, 8, 10, 15]

There have been a number of attempts to treat the totally abnormal return all aiming to direct the pulmonary flow to the left atrium but attempting to do this by several different methods. Muller[19] first reported partial correction by anastomosis of the venous trunk from the left lung to the left atrial appendage, and complete correction of several types of totally abnormal return has since been reported.[6, 8, 11, 16, 19] The purpose of this report is to describe our surgical experiences with 35 cases of anomalous pulmonary venous return in 16 of which all the pulmonary veins drained abnormally. These represent 38 per cent of the 92 patients treated during the past 9 years for anomalous venous return or atrial septal defect, the condition which the former most resembles clinically.

EMBRYOLOGY

The current, most widely held explanation of the developmental abnormality states that the pulmonary venous plexus arises from differentiation of the splanchnic plexus around the developing lung.[1, 21] The primordial cardiac end of the pulmonary vein develops as a small endothelial pouch growing from the atrium on the left of the developing septum and extending toward the pulmonary plexus. Simultaneously, the systemic veins are developing from fusion of the anterior and posterior cardinal veins on either side to form the common cardinal vein or duct of Cuvier. Both common cardinal veins join the sinus venosus. This later is absorbed into the heart, the right common

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cardinal vein becoming the proximal portion of the superior vena cava, the right posterior cardinal vein becoming the azygos, and the right anterior cardinal vein the superior vena cava distal to the azygos. The left common cardinal vein is absorbed into the heart as the coronary sinus. More distally, the left common cardinal vein becomes the oblique vein of Marshall and the primitive posterior cardinal vein persists as the highest intercostal vein. Should the pulmonary plexus and the pulmonary vein extending out from the atrium fail to meet, these systemic veins or their remnants form ready substitutes. The connections are already present joining the splanchnic-pulmonary plexus to the cardinal system.

Neill's grouping of anomalies of the pulmonary venous system is convenient for surgical purposes. She suggests that drainage of the pulmonary veins into the *right atrium* might occur, if the atrial septum develops abnormally far to the left. Drainage into the *right superior vena cava,* azygos, or right innominate vein would represent persistence of communication between the pulmonary venous plexus and the right horn of the sinus venosus and right common cardinal vein. Drainage into a persistent *left superior vena cava,* coronary sinus, or left innominate vein might result from persistence of connections with the left common cardinal system. In such an instance, once the pulmonary venous plexus communicates with the left horn of the sinus venosus and left cardinal system, three possibilities arise. The cardinal system may atrophy proximal to the entrance of the pulmonary veins, in which case the pulmonary veins will drain into a left innominate, or a persistent left superior vena cava (or left vertical vein). If the cardinal system atrophies distal to the entrance of the pulmonary veins, the ultimate connection is to the coronary sinus. In some instances, the entire cardinal system persists and the pulmonary veins empty into a left superior vena cava connecting with the coronary sinus as well as the innominate. Neill's fourth group consists of connection with the portal vein or ductus venosus, remnants of early drainage into the umbilicovitelline system.

In all instances, except anomalous drainage into the right atrium, it is presumed that the primordial pulmonary vein does not develop in the atrium, does not establish contact with the developing pulmonary plexus, or loses this connection once made.

Edwards and associates[18] have added an additional group of patients in which the connections of the common pulmonary vein to the left atrium are abnormal, although all the pulmonary venous blood may return to the left side. In such a case, a tri-atrial heart arises with two chambers in the left supraventricular region, the upper one arising from the common pulmonary vein, the lower from the left atrium, and the septum between being the narrowed junction of pulmonary vein and atrium. This condition will not be included in the subsequent discussion.

DIAGNOSIS

When one or two of the pulmonary veins drain directly into the right atrium and the remainder normally to the left, the clinical picture may be identical with that of a simple atrial septal defect. It has been stated that partial anomalous venous return is associated with higher pulmonary blood flows and pressures than those seen with simple atrial septal defect, but this has not been a consistent finding in the present series. We have noted, however, in the electrocardiogram of these patients, a more marked degree of right ventricular hypertrophy than is usually associated with a simple atrial defect with comparable pulmonary artery pressures. The correct diagnosis of the partial anomaly may be suggested by electrocardiogram, by the occasional visualization of the anomalous vein on the plain roentgenogram, by the catheterization of the vein or veins directly from the right atrial wall or superior vena cava, or by visualization with angiocardiography. Swan and associates[5] have developed methods, including the injection of indicator dyes, by which one may determine whether the drainage is anomalously to the right side of the heart. In some instances of simple atrial defect, however, the drainage from one or the other lung may be predominantly to the right. Thus, they point out a distinction between abnormal venous drainage and abnormal venous connection, the two not necessarily being the same.

In the presence of a totally abnormal pulmonary venous drainage both systemic and pulmonary venous blood mix in the right atrium so that blood in all other cardiac chambers is of similar oxygen saturation. In some instances due to streaming, pulmonary blood may contain a higher oxygen content than systemic arterial. *Such patients must have peripheral arterial unsaturation* although with a high pulmonary flow this may be of such small degree that it is not noticed clinically without analysis of arterial blood. The total anomaly is most apt to cause symptoms and failure early in life and be associated in the absence of failure with excessive pulmonary blood flow and greater tendency to increased pulmonary vascular resistance. In Keith's series[14] the majority of the patients died before 6 months. The size of the atrial septal defect, or foramen ovale, is probably important in the onset of failure forming an obstruction when small. In addition, the left atrium and ventricle are usually underdeveloped.

Since anomalous drainage of the pulmonary veins into the *right atrium* complicates the operative problem only very little, it is not of great surgical importance to identify the anomalous veins prior to operation. The anomalous return in Case 1 in which all pulmonary veins entered the right atrium was strongly suspected because of the unusual disability, the large shunt into the atrium, and slight arterial unsaturation.

When the anomalous drainage is into the *superior vena cava*, the anomalous veins may be seen on a plain roentgenogram in a slightly higher than normal position (Fig. 1, *A*). This can be confirmed by angiocardiography or by cardiac catheterization when arterialization is discovered in this region, more readily demonstrable when the drainage is high in the vena cava or into the innominate. When all pulmonary veins enter the superior vena cava, this structure usually shows dilatation radiologically.

Drainage of the pulmonary veins into the *coronary sinus* may be accompanied by great cardiac enlargement and severe cardiac failure

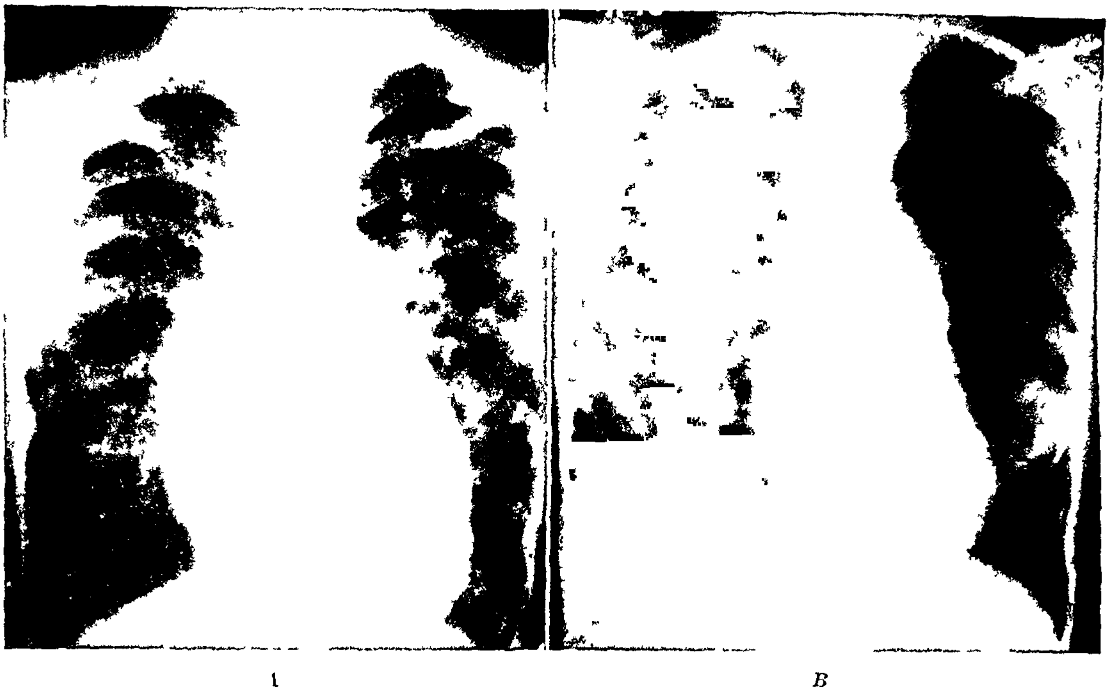


Fig. 1.—Case 25. Pre- and postoperative roentgenograms (A and B, respectively). The pulmonary vascular markings enter the cardiac silhouette on the right at a slightly more rostral level than normally. Much of the cardiac enlargement is due to the right atrium.

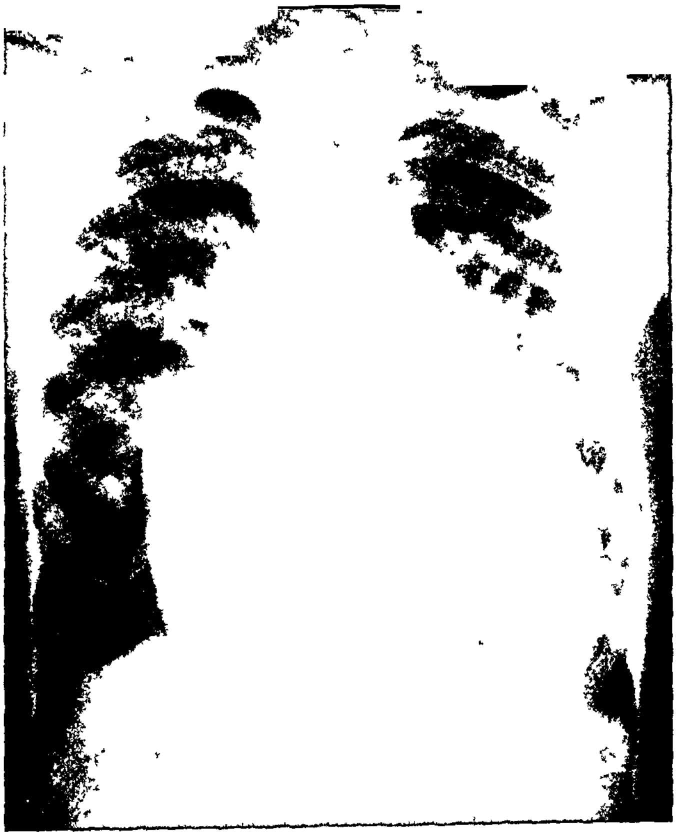


Fig. 2.—Case 28. Total pulmonary venous drainage to the coronary sinus. The boxlike shelf to the upper right border is characteristic on the roentgenogram.

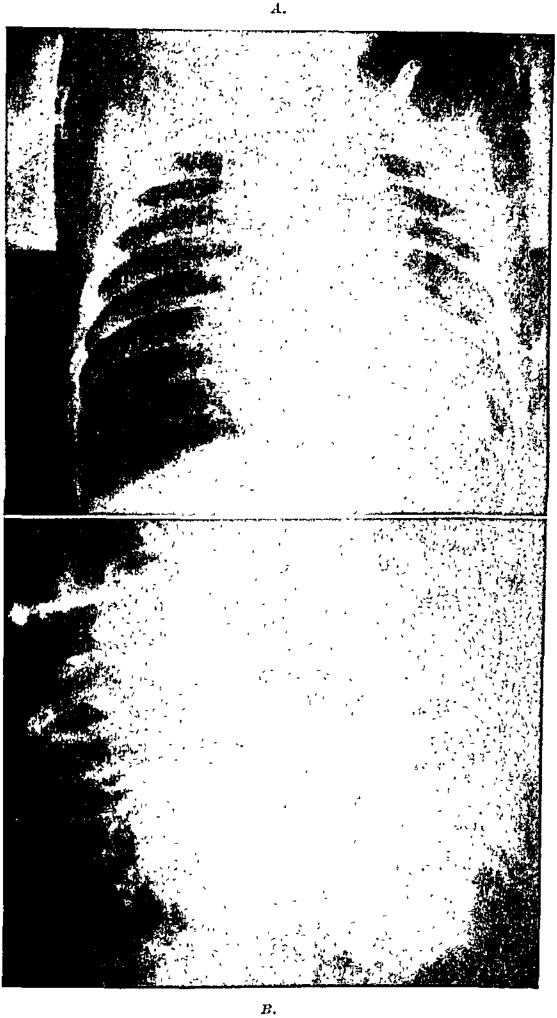


Fig. 3.—Case 34. Total anomalous drainage into left superior vena cava in an infant. The "snowman" appearance is not readily evident on the plain roentgenogram but is clearly seen on the angiocardiogram.

childhood. The contour of the heart is unusual, the right atrium being large and boxlike with a somewhat horizontal upper border (Fig. 2). This contour when present appears characteristic but unfortunately was absent or had not yet appeared in the one infant encountered with this condition.

When all pulmonary veins drain to the *left superior vena cava,* there is a "snowman" or "figure-of-eight" appearance on the roentgenogram which has been extensively illustrated and is due to the dilated left superior vena cava (or vertical vein), innominate vein, and right superior vena cava, together forming a rounded shadow above the globular heart. This typical radiologic appearance is less easily recognized in infants (Fig. 3, *A*) but may be readily demonstrated angiocardiographically (Fig. 3, *B*) or by catheterization with the shunt demonstrable into the innominate vein.

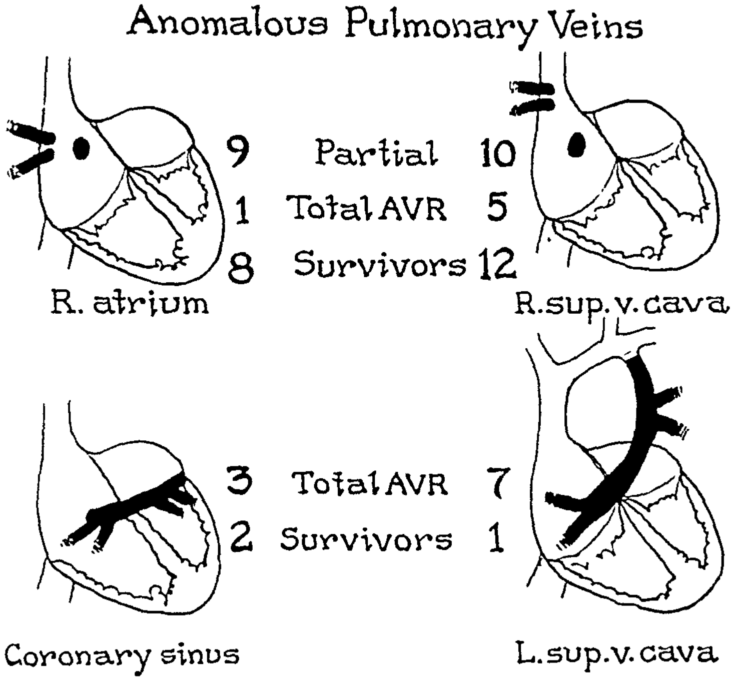


Fig. 4.

SURGICAL TREATMENT

The subsequent discussion is based upon experience as follows: There were 10 cases in which pulmonary veins entered the right atrium, in one instance both right and left sides draining anomalously. In 10 cases, some or all of the right pulmonary veins drained into the superior vena cava and in 5 all pulmonary veins from both lungs drained into a chamber which entered the right superior vena cava. All pulmonary veins drained to the coronary sinus in 3 cases and in 7 cases all pulmonary veins entered a persistent left superior vena cava (Fig. 4 and Table I).

The present method of hypothermia used with most of these cases has been reported[24] but consists of surface cooling to 30° to 32° C., mild alkalosis

TABLE I

NAME AND NO	AGE	METHOD OF REPAIR	OTHER ANOMALIES	RESULT	REMARKS
		Pulmonary Veins Entering Right Atrium			
Totally Anomalous					
Case 1 S H 717950	15	Hypothermia, direct suture	None	Good	Total anomalous return to right of septal rim, septum incised to effect transposition of veins
Partially Anomalous					
Case 2 E B 626696	14	Atrial well	Pulmonary thrombosis	Died	Severe pulmonary hypertension and thrombosis
Case 3 C A 736541	13	Hypothermia, direct suture	None	Good	Superior pulmonary vein anomalous
Case 4 L F 662181	5	Hypothermia, direct suture	None	Died	Unexplained severe acidosis, right inferior pulmonary vein anomalous, earlier attempt to close defect with purse string unsuccessful and sutures subsequently removed because of infection
Case 5 N M 768002	6	Hypothermia, direct suture	None	Good	Septum incised to effect transposition of all right pulmonary veins
Case 6 F A 742498	7	Hypothermia, direct suture	None	Good	Anomalous right inferior pulmonary vein only
Case 7 R B 622376	11	Hypothermia, direct suture	None	Good	Right superior and middle veins anomalous
Case 8 B B 675489	10	Hypothermia, direct suture	Left SVC	Good	All right pulmonary veins into right atrium septum incised to transpose veins
Case 9 L J 760337	19	Hypothermia, direct suture	None	Good	1 cm foramen ovale both right pulmonary veins into right atrium septum incised to effect closure
Case 10 P McL *	21	Hypothermia direct suture	None	Good	Right superior pulmonary vein anomalous, septum incised to effect transposition of veins
		Right Pulmonary Veins Into Right Superior Cava			
Case 11 J T 633834	6	Atrial well	None	Died	Died shortly after opening atrial well
Case 12 E B 735041	45	Partition of cava, purse string	None	Good	Superior and middle lobe veins anomalous
Case 13 E B 701657	7	Hypothermia, partition	None	Good	Superior pulmonary vein anomalous, SVC pressure 12 mm Hg after closure

*Treated at the Royal Prince Alfred Hospital Sydney Australia

Cont'd on next pages

TABLE 1—CONT'D

NAME AND NO.	AGE	METHOD OF REPAIR	OTHER ANOMALIES	RESULT	REMARKS
Case 14. M. S. 639709	12	Hypothermia; partition	None	Good	Superior pulmonary vein anomalous; SVC pressure 12 mm. Hg after closure
Case 15. B. M. 716418	15	Hypothermia; partition	None	Good	Superior pulmonary vein anomalous; SVC pressure 26 mm. Hg after closure
Case 16. P. B. 741548	11	Hypothermia; partition	None	Good	Superior pulmonary vein anomalous
Case 17. C. W. 796284	7	Hypothermia; partition	None	Good	Superior and middle lobe veins anomalous; SVC pressure 20 mm. Hg after closure; postoperative chylothorax
Case 18. A. F.*	33	Hypothermia	Left SVC	Good	Superior and middle lobe veins anomalous; right SVC directed into septal defect under direct vision; right SVC ligated above; left SVC present
Case 19. L. H. 783712	11	Hypothermia	Left SVC	Good	Same as Case 18
Case 20. R. J. 602898	31	Hypothermia; partition	None	Good	Superior and middle lobe veins anomalous
All Pulmonary Veins Draining to Right Superior Cava					
Case 21. K. F. 506600	4	None	None	Died	Exploration on right only, in 1949; later anastomosis on left planned; right pulmonary artery coursed between common pulmonary vein and left atrium
Case 22. R. B. B 03237	6/12	Atrial well	None	Died	Anomaly not fully diagnosed until autopsy; arrest on closure of foramen ovale
Case 23. E. C.	7	Purse string; partial ligation of cava	None	Incomplete repair	Right SVC directed through septal defect to left atrium; SVC obstructed above entrance of veins
Case 24. D. D. 613723	7	Hypothermia; partition	None	Good	Right pulmonary artery coursed between left atrium and common pulmonary vein; SVC pressure rose 2 mm. Hg
Case 25. B. L. 604034	13	Hypothermia; partition	None	Good	Initial repair obstructed pulmonary veins; revised with another period of inflow occlusion
All Pulmonary Veins Draining to Coronary Sinus					
Case 26. J. R. 475646	13	Bypass	Patent ductus, tricuspid insufficiency	Good	Small foramen ovale; Septum removed between coronary sinus and left atrium, resulting defect of atrial septum sutured

TABLE 1—CONT'D

NAME AND NO		AGE	METHOD OF REPAIR	OTHER ANOMALIES	RESULT	REMARKS
Case 27	D H B 38052	2	Hypothermia	None	Died	Severe cardiac failure, died after exploration with inflow occlusion
Case 28	F A 784086	15	Bypass	None	Good	As in Case 26, initial repair obstructed pulmonary veins, revised with additional bypass
		All Pulmonary Veins Entering Left Superior Cava				
Case 29	J G 508089	2	Left atrial left pulmonary vein anastomosis	None	Died	Anastomosis of left inferior pulmonary vein to atrial appendage, trunk constricted rostrally
Case 30	C B	4	Left atrial left pulmonary vein anastomosis	None	Died	Anastomosis of left atrial appendage to venous trunk, constriction rostrally
Case 31	A S A 95474	4/12	Left atrial left pulmonary vein anastomosis	None	Died	Anastomosis of left atrial appendage to venous trunk, constriction rostrally
Case 32	B B 681276	28	Left atrial left pulmonary vein anastomosis	None	Died	Aortic graft used to join left atrium and venous trunk
Case 33	T H B 36459	10/12	Hypothermia	None	Died	Attempted transposition of right SVC to foramen ovale, improper suture
Case 34	N B B 14197	3/12	Bypass	None	Died	Small infant in severe failure, attempted transposition of right SVC
Case 35	J D *	20	Bypass	None	Good	Right SVC directed to left atrium through foramen ovale, azygos and right innominate veins ligated

by hyperventilation and gravity perfusion of the coronary arteries during inflow occlusion. Two periods of inflow occlusion of 9 minutes each were used in Case 26 but, in most instances repair was accomplished in less than 8 minutes.

The pump oxygenator used for cardiopulmonary bypass was the stationary screen oxygenator as modified by Gaertner and Kay.

In most instances, operation has been performed through the right chest only, the fourth interspace being entered. When additional exposure is required, as for visualization of the left superior vena cava, the sternum may be transected but rarely does the left chest need to be entered for treatment of anomalies on the right side. In earlier experience in attempting to anastomose the auricular appendage to the persistent left superior vena cava, an approach through the left side was, of course, used.

The importance of thorough dissection and visualization of all vessels in the operative field cannot be overemphasized. Although, in some cases, anomalous pulmonary veins were suspected from clinical or catheterization data, in most instances the partial anomalous drainage was first diagnosed with certainty only after such dissection. One should be certain of visualizing veins draining all areas of the exposed lung, and clearly identify, within the pericardium or at the site of entering the superior vena cava, the termination of such veins. The position of veins can then be further delineated by palpation within the heart through an incision in the wall of the atrium or the tip of the atrial appendage. In palpating within the heart a plan should be developed, our own being to examine the superior and inferior venae cavae, coronary sinus, the atrial septum and, if the septum is not intact, the origin of right and left pulmonary veins through the defect, the left atrial appendage, the mitral valve, and the tricuspid valve. Accurate examination of all these structures is not possible in infants with small hearts and it is our belief that particularly in such children open visualization is needed; this requires additional time of circulatory interruption and hence a cardiopulmonary bypass should be used.

Pulmonary Veins Entering Right Atrium (Table I).—When pulmonary veins drain anomalously into the right atrium in the region of an auricular septal defect no difficulty is usually encountered in suturing the anterior rim of the defect to the right of the pulmonary veins in the repair. In some instances, veins enter the right auricle just above or below the defect and adjacent to intact septum. In such instances, incision of the septum is required; this should be done posteriorly, adjacent to the orifice of the anomalous vein, and this flap of septum may then be sutured anterior and to the right of the pulmonary veins (Fig. 5). In one patient (Case 1), treated under hypothermia, the rim of the septal defect was unusually far to the left and all right and left pulmonary veins drained into the right atrium to the right side of this septal rim. Regardless, after incision to enlarge the defect, the anterior rim of the septum could be sutured to the right of the pulmonary veins thus completely correcting the totally anomalous return (Fig. 6).

In the 92 patients operated upon, with a left-to-right shunt in the atrium who form the subject of this review, including both atrial defect and anomalous venous drainage, there have been 10 in whom along with an atrial septal defect one or more pulmonary veins drained directly into the right atrium, including the one mentioned above in which all veins drained to the right. In 3 instances the superior and middle lobe veins were the only anomalous ones, in 3 the inferior vein alone and, in the other 4 cases, all right pulmonary veins entered the right atrium. When anomalous veins enter the atrium adjacent to a vena cava it is important to place an initial suture under direct vision and then be certain the cava is not obstructed, possibly by releasing the caval occlusion.

Two of these 10 patients died of conditions probably unrelated to the anomalous pulmonary venous return. In one (Case 2), there was extensive preoperative thrombosis of the pulmonary arteries with thrombus in the atrium and severe pulmonary hypertension. The other patient (Case 4), previously reported,[2] had been treated earlier by a closed method, at which time

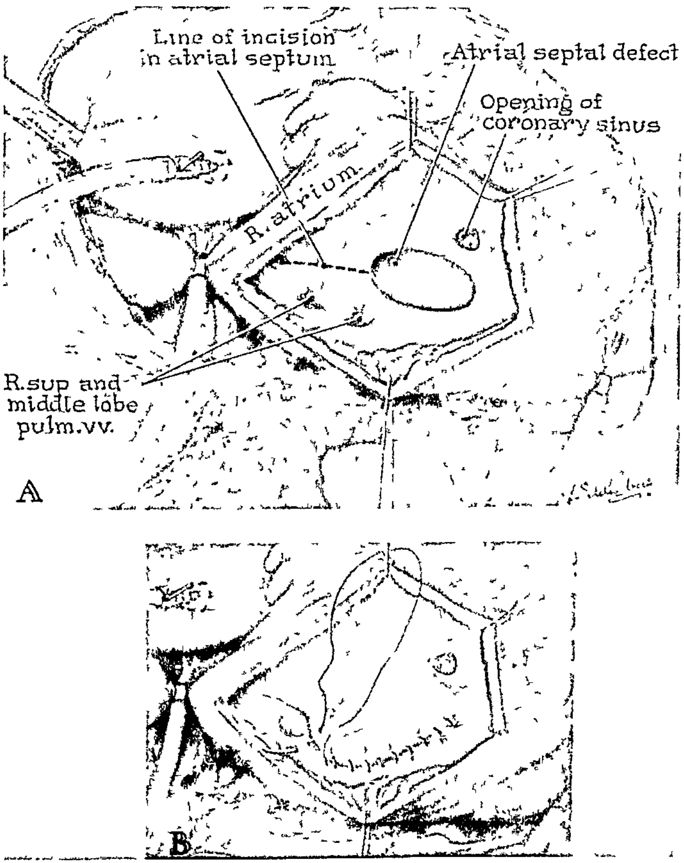

Line of incision in atrial septum
Atrial septal defect
Opening of coronary sinus
R. atrium
R.sup and middle lobe pulm.vv.
A
B

Fig. 5—Anomalous pulmonary return to the right of an atrial septal defect. *A*, Incision of the adjacent septum is done posteriorly so that the flap of septum created can be readily sutured anterior and to the right of the entrance of the pulmonary veins (*B*)

it was not possible to correct completely the anomalous return of the inferior pulmonary vein, in addition, she developed infection about the sutures. At the second attempt to repair the defect, this time under hypothermia, fibrillation occurred which was reverted to normal rhythm but th[illegible]as poor cardiac recovery and later death. Later analysis of blood drawn for pH before the period of circulatory occlusion demonstrated a profound acidosis. We do not have an adequate explanation for this event, the only time in our experience in which such acidosis has occurred.

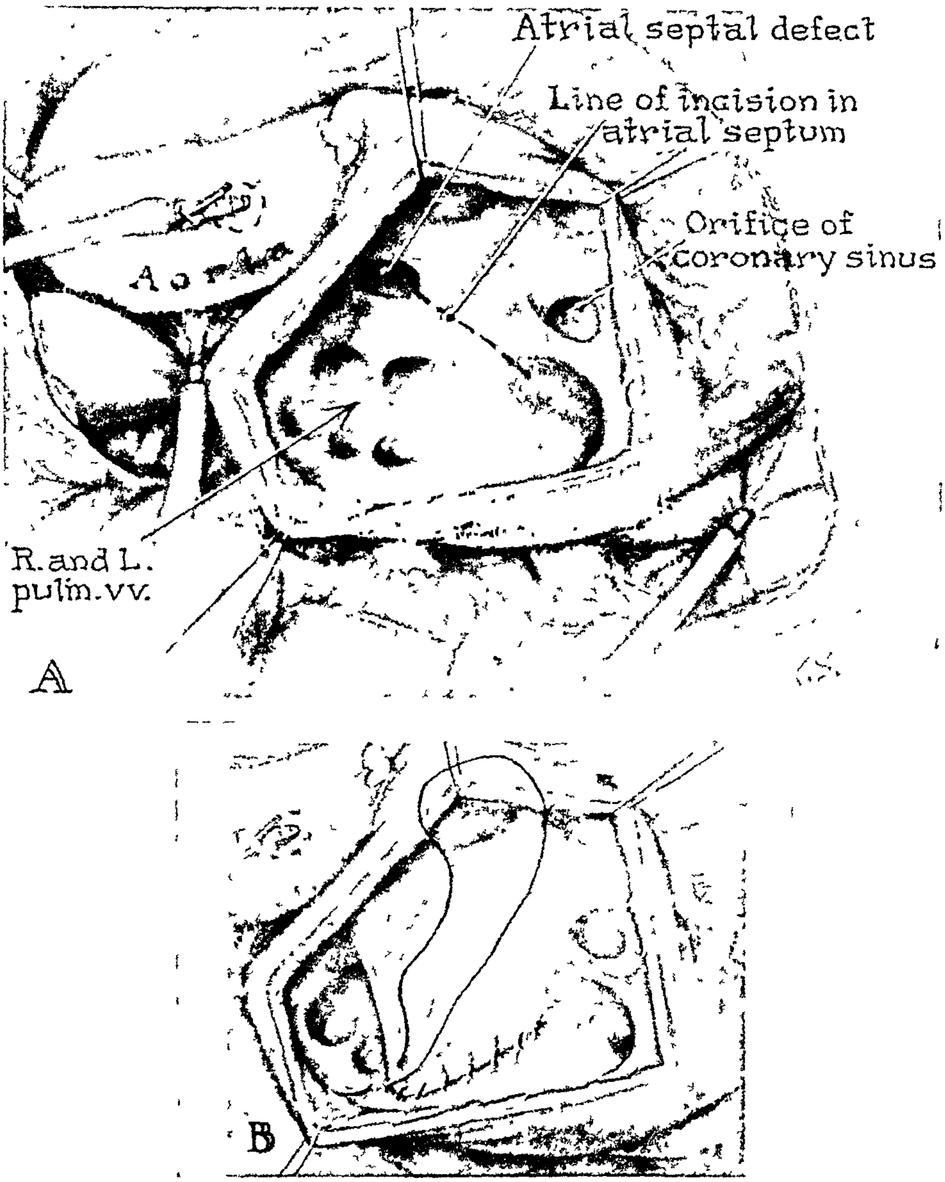


Fig. 6.—Case 1. Total anomaly of the pulmonary veins to the right of the atrial septum with a 1 cm. foramen ovale Complete repair was effected by incision of the septum and suture to the right atrial wall (*B*).

Right Pulmonary Veins Into Right Superior Cava (Table I).—Fifteen patients have been treated with anomalous drainage into the right superior vena cava, in 5 of whom all pulmonary veins drained anomalously. The first (Case 21) was explored on the right, in 1949. After visualization of the abnormality the chest was closed with the intention of later anastomosis of the left venous trunk to the left atrium. She died in the postoperative period. The second of these (Case 22) was not fully diagnosed until autopsy, the foramen ovale having been sutured through the atrial wall. The third (Case 23) had a total anomaly with all of the veins draining into a common pulmonary venous chamber which emptied into the superior vena cava near the entrance of the azygos vein (Fig. 7 A). He was treated by a closed method in which a purse-string suture was used to approximate the caudal edge of the defect to the lateral wall of the right atrium, and the superior vena cava was partially obstructed above the point of entrance of the pulmonary veins (Figs. 7 A and 7 B). By this means, the pulmonary blood was directed to the left atrium along with a partial return from the superior vena cava. Obstruction of the superior

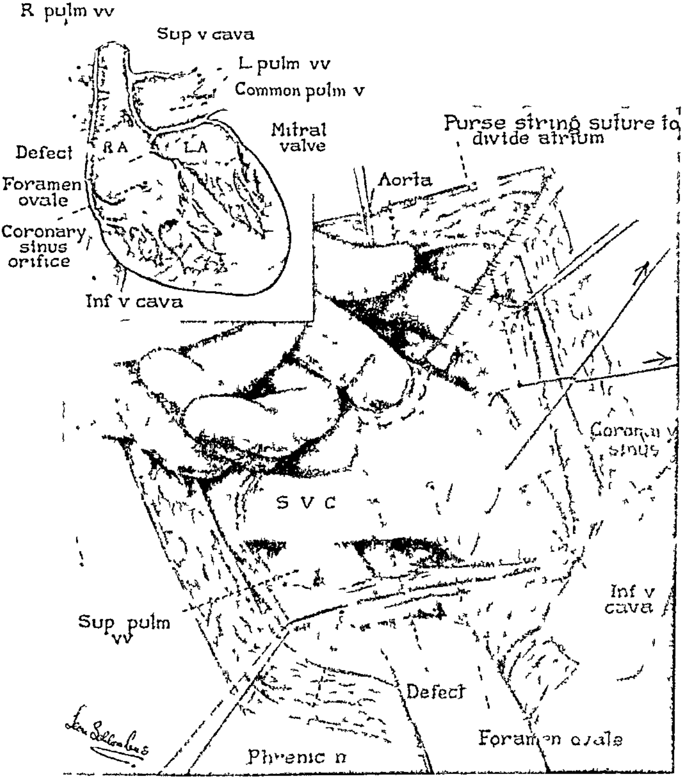
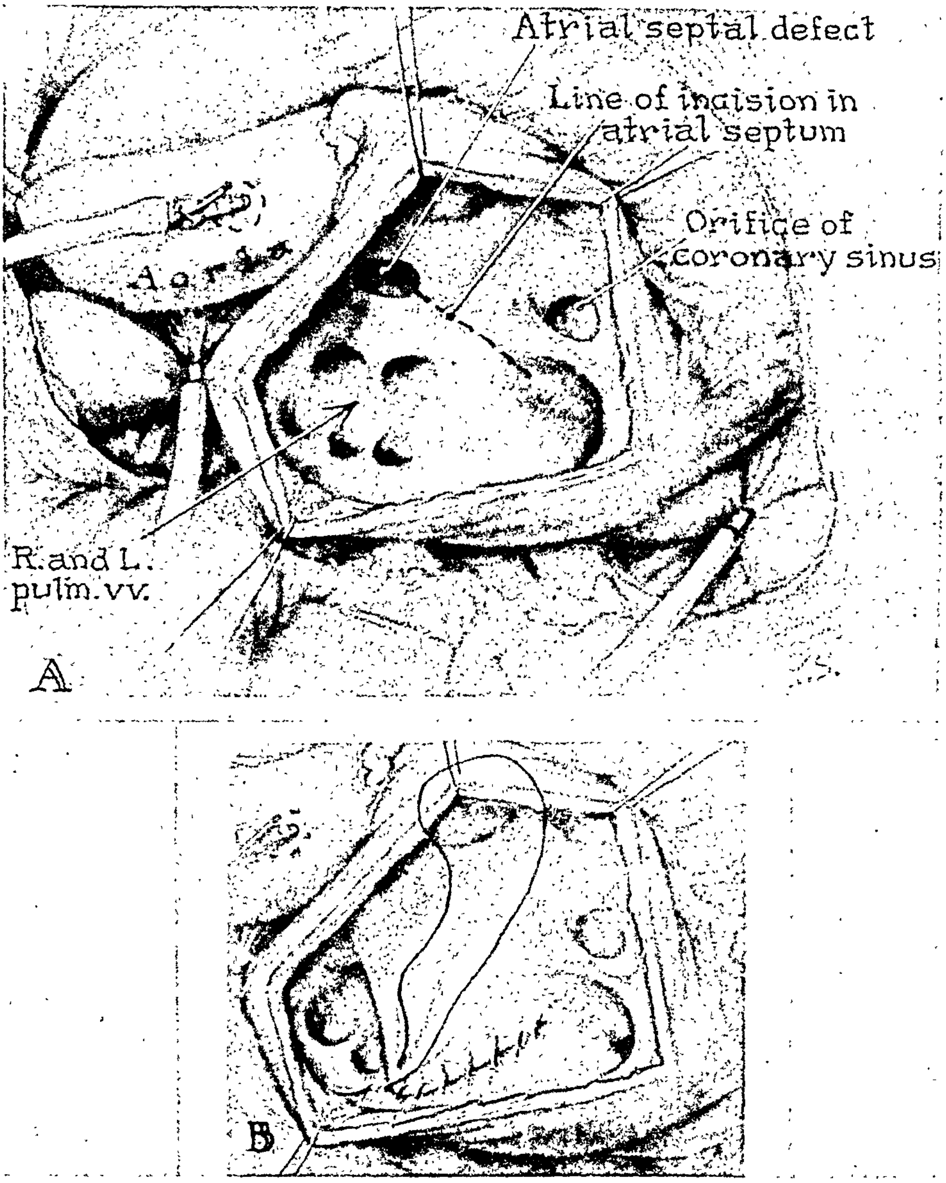


Fig. 7A.—Case 23. Drainage of all pulmonary veins to a common vein entering the superior vena cava. Attempted correction by closed procedure and a purse-string suture directing the superior vena caval and pulmonary flow through the septal defect to the left atrium.

recovery and later death. Later analysis of blood drawn for pH before the period of circulatory occlusion demonstrated a profound acidosis. We do not have an adequate explanation for this event, the only time in our experience in which such acidosis has occurred.



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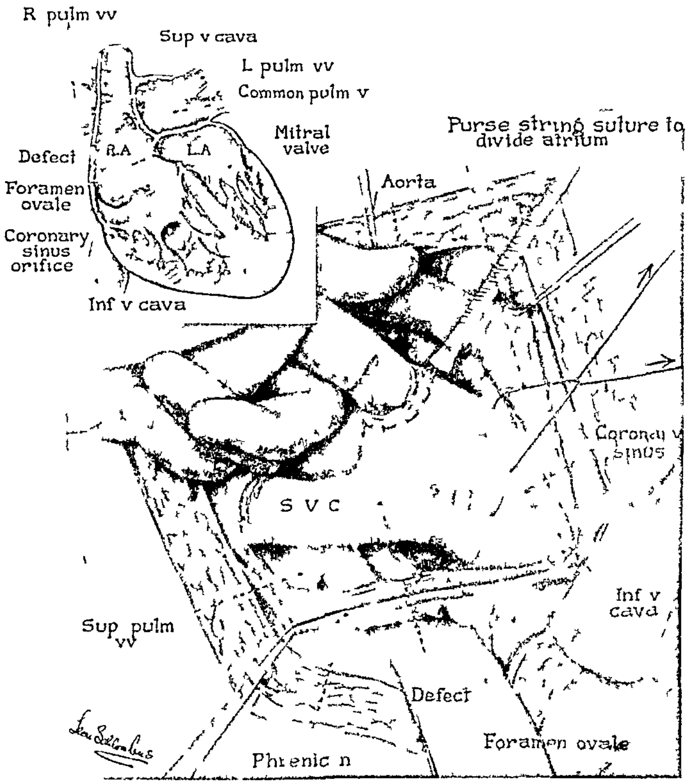


Fig 7 A.—Case 23. Drainage of all pulmonary veins to a common vein entering the superior vena cava. Attempted correction by closed procedure and a purse string suture directing the superior vena caval and pulmonary flow through the septal defect to the left atrium.

azygos vein (Fig 7 *A*). He was treated by a closed method in which a purse-string suture was used to approximate the caudal edge of the defect to the lateral wall of the right atrium, and the superior vena cava was partially obstructed above the point of entrance of the pulmonary veins (Figs 7 *A* and 7 *B*). By this means, the pulmonary blood was directed to the left atrium along with a partial return from the superior vena cava. Obstruction of the superior vena cava thus required development of collateral vessels from the superior to the inferior vena cava. Except for the patient's unwillingness to lie flat in the postoperative period and the development of superficial venous collaterals there was no evident detriment to him as a result of this procedure. Catheterization 30 months later, however, showed incomplete correction of the abnormality.

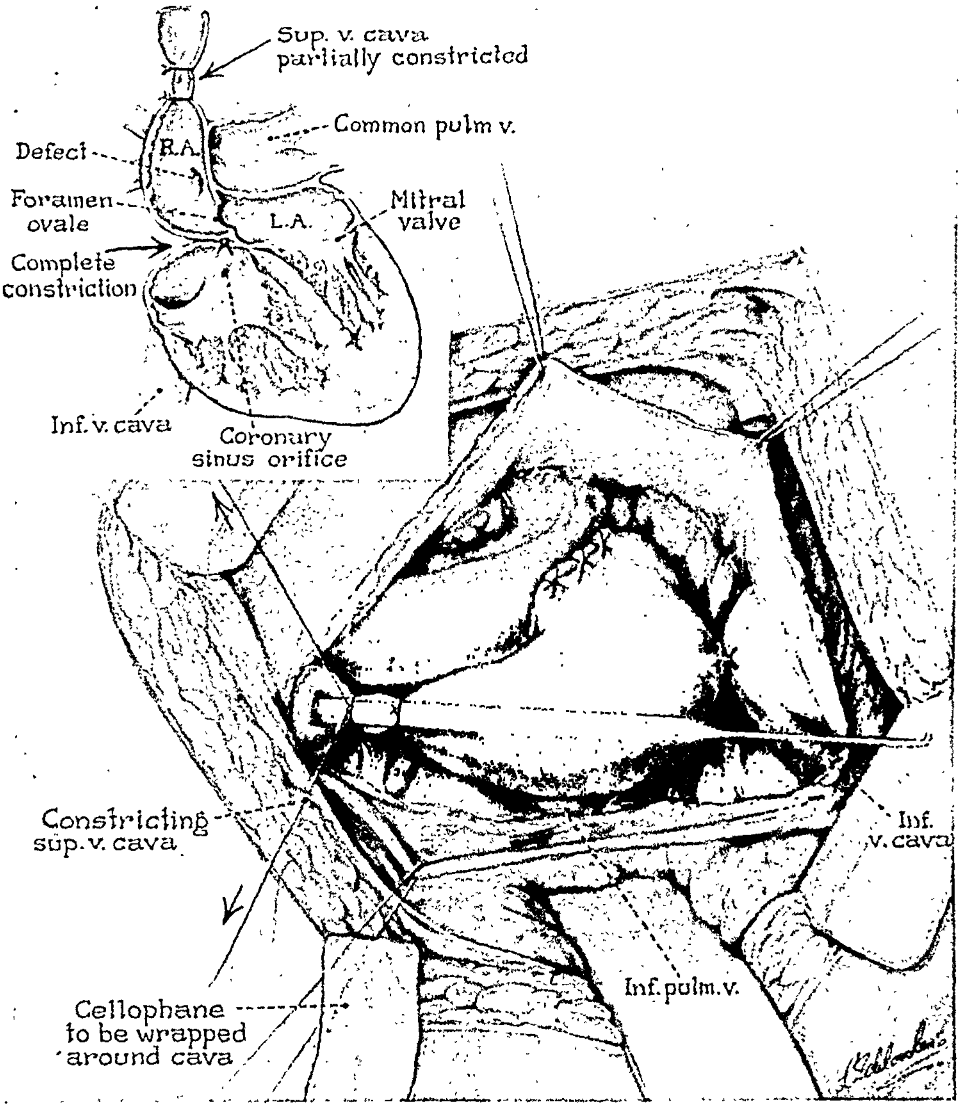


Fig. 7*B*.—Correction completed. The superior vena cava was constricted to reduce the amount of systemic venous blood entering the left atrium.

In subsequent patients, either with a partial or complete anomaly, the superior vena cava has been partitioned so that pulmonary venous blood is directed through the septal defect into the left atrium and the orifice of the superior vena cava is directed anteriorly into the right atrium. After exploratory palpation of the defect the finger has been removed and the sutures for the partition placed from the outside. When suturing in the vena cava has been completed the venae cavae are occluded and the repair completed under direct vision (Fig. 8). In all cases, the septal defect has been a high one near the orifice of the superior vena cava.

This partitioning imposes some obstruction to the superior caval drainage but this vessel in association with anomalous return has been unusually large and adequate room was usually available. Pressures have been measured in both right and left atria and the superior vena cava after surgical partitioning and usually show an increase of 5 to 12 mm. Hg in the superior caval pressure above that in the right atrium. In only one instance has a significant complication arisen as a result of the caval sutures, the development of a chylothorax, presumably as a result of later further obstruction of the superior cava by thrombosis. All patients treated by the partitioning method survived.

Two patients with drainage of all pulmonary veins into the right superior vena cava have been treated by partitioning the superior cava and directing the pulmonary venous blood through the high atrial defect with good result.

A logical and simple solution to this defect would seem to be excision of the partition between the pulmonary venous chamber and the left atrium and closure of the resulting larger atrial and superior caval defect. Although this would have been possible in 3 of the 5 patients, it would seem impossible in the other 2 as the pulmonary artery coursed between the pulmonary venous chamber and the left atrium (Fig. 9).

In 2 patients (Cases 18 and 19), the fortunate combination of anomalous drainage into the right superior vena cava and the persistence of a left superior vena cava allowed obstruction of the right cava with impunity. In both of these instances the rim of the atrial defect was simply sutured to the anterior edge of the superior cava, thus directing all of the caval blood to the left side, and the right superior cava was ligated cephalad to the entrance of the anomalous veins but caudad to the entrance of the azygos vein (Fig. 10).

All Pulmonary Veins Draining to Coronary Sinus (Table I).—Total anomalous pulmonary venous drainage into the coronary sinus has been seen in 3 patients (Cases 26, 27, 28). In all of these, the anomaly could be easily corrected under direct vision by excision of the partition between the coronary sinus and the left atrium and closure of the single atrial defect, in essence, converting the double-barreled opening into a single one, the coronary sinus orifice being unusually large (Fig. 11). In one of the patients, a sufficient portion of the septum was not excised at the initial attempt and systemic hypotension with elevation of the pulmonary venous pressure was noted when the cardiopulmonary flow was restored. The bypass was again used and an additional portion of the septum removed so that ultimately there was little gradient of pressure between the pulmonary veins and the left atrium. Two of the patients have obtained a good result from the procedure. The third patient was an infant in whom the true state of the anomaly was not appreciated before operation and an attempt to repair the atrial defect was done under hypothermia. It was recognized that the left pulmonary veins drained into the coronary sinus but mistakenly thought that the right veins drained into the right. After 8 minutes of exploration under direct vision with caval

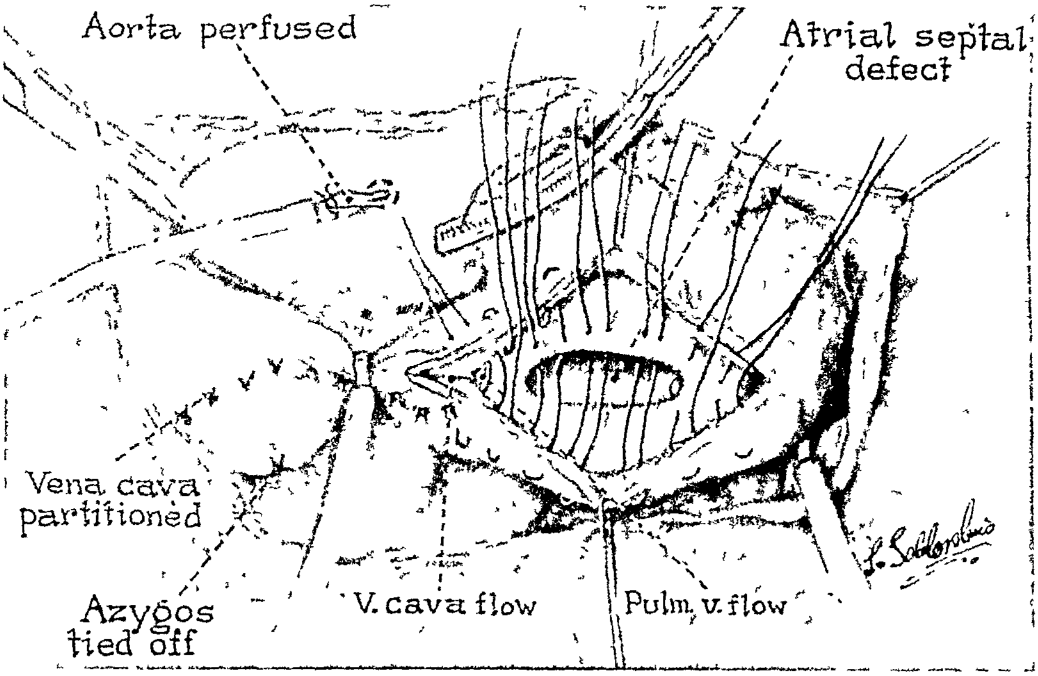


Fig. 8.—Currently employed method for correction of drainage to superior vena cava. The superior vena cava is partitioned, the pulmonary drainage being posterior and the systemic drainage anterior. After partitioning into the upper part of the atrium the repair is completed under direct vision and inflow occlusion with coronary perfusion.

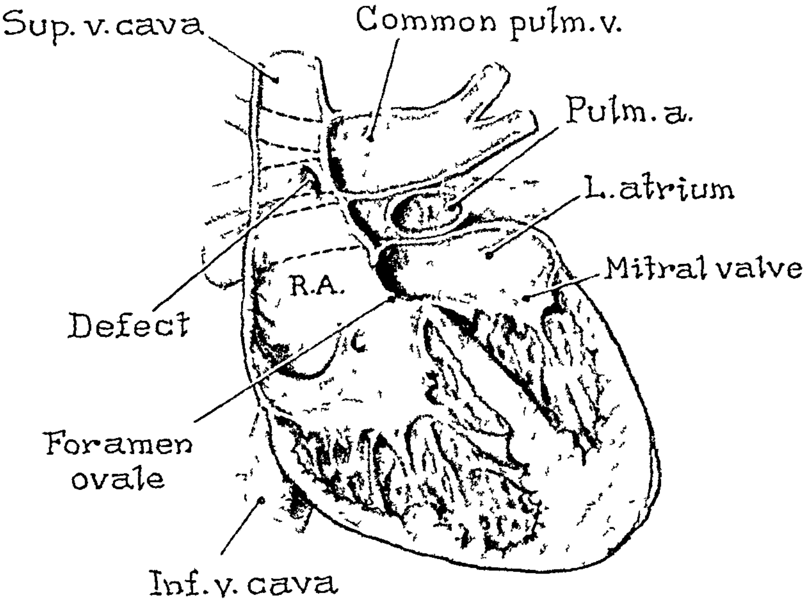


Fig. 9.—Anomaly present in 2 of the 5 cases with total drainage into the superior vena cava. The passage of the right pulmonary artery between the atrium and the common pulmonary vein would preclude excision of the septum between them in the repair.

occlusion, the circulation was re-established with the intention of a second period of occlusion for repair of the defect. Cardiac action deteriorated, however, and repair was not possible, the child subsequently dying.

In one case, an unusual atrial defect led to the preoperative suspicion of anomalous return into the coronary sinus, largely because of dilution of contrast material in the lower end of a left superior vena cava. At operation during cardiopulmonary bypass, a defect was found between the left atrium and the large coronary sinus (Fig. 12). The pulmonary veins drained normally. The absence of right-to-left shunt and peripheral arterial unsaturation, cardiomegaly, and great right atrial enlargement should lead to the correct diagnosis in such a case.

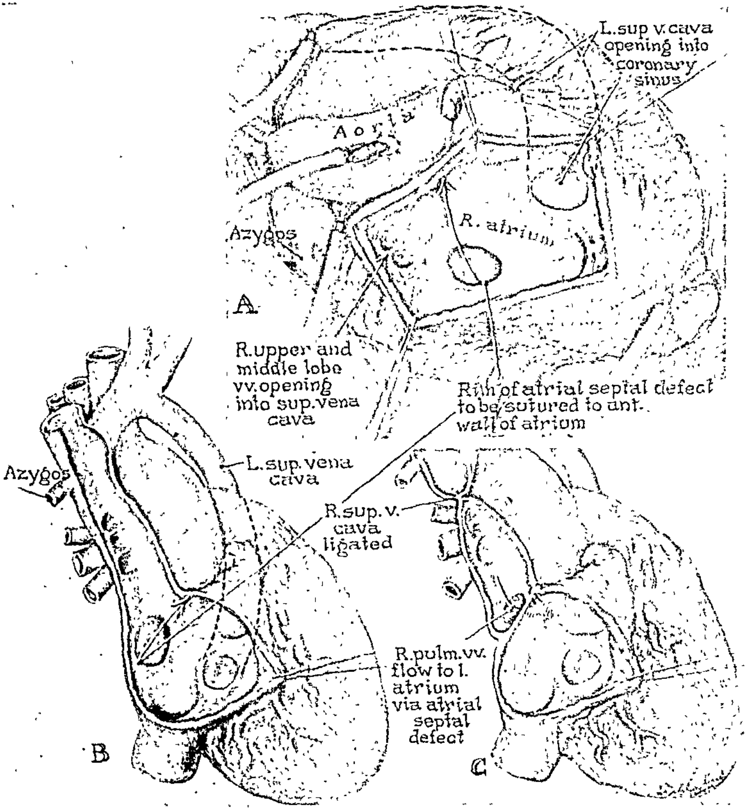
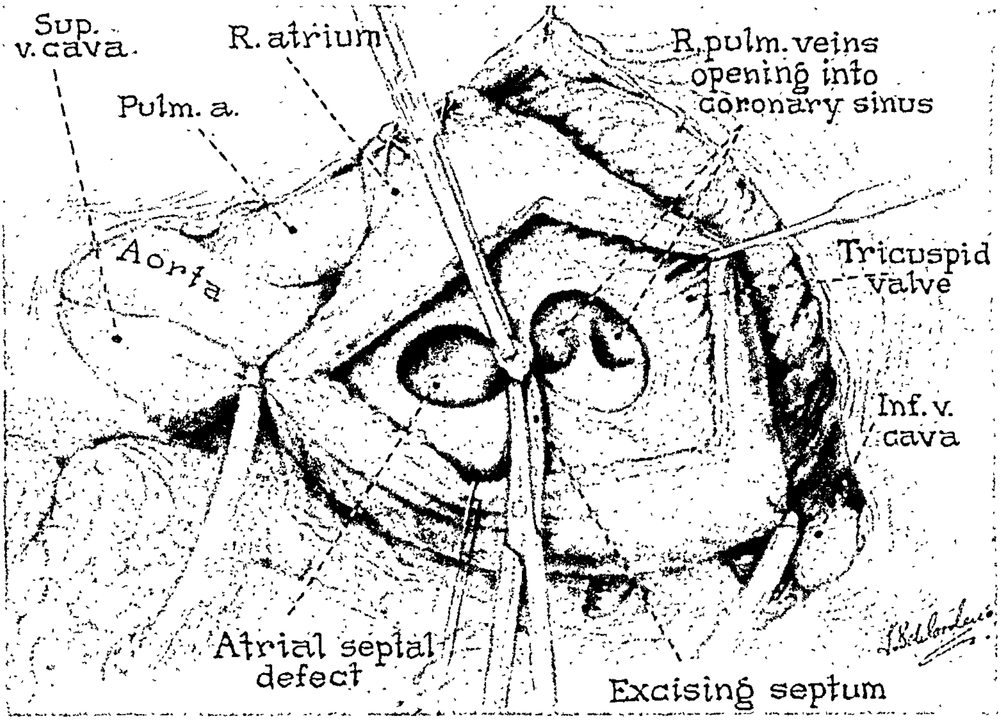
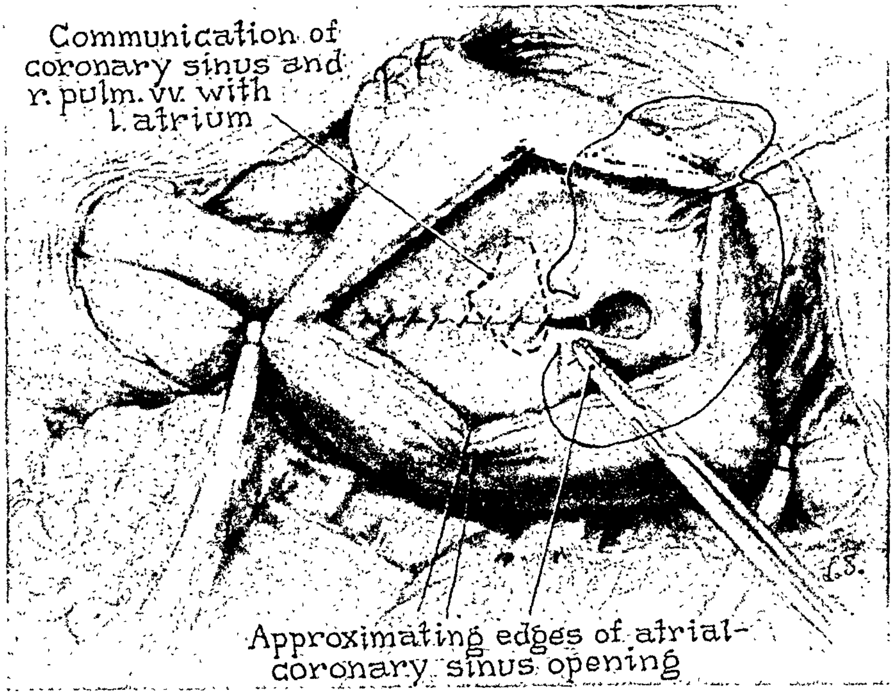

L. sup v. cava opening into coronary sinus
Aorta
R. atrium
Azygos
A
R. upper and middle lobe vv. opening into sup. vena cava
Rim of atrial septal defect to be sutured to ant. wall of atrium
Azygos
L. sup. vena cava
R. sup. v. cava ligated
R. pulm. vv. flow to l. atrium via atrial septal defect
B
C

Fig. 10.—Cases 18 and 19. Drainage of the right lung into the superior vena cava, with persistent left superior vena cava. The right superior cava was ligated without detriment and the pulmonary venous drainage directed through the atrial defect to the left side.



A.


Communication of coronary sinus and r. pulm. vv. with l. atrium
Approximating edges of atrial-coronary sinus opening

B.

Fig. 11.—*A*, Total pulmonary venous drainage to the coronary sinus. Tissue between the coronary sinus and the left atrium was excised.

B, The resulting larger atrial septal defect closed in the usual fashion.

All Pulmonary Veins Entering Left Superior Cava (Table I).—One of the commonest total anomalies has been that in which all pulmonary veins drain into the persistent left superior vena cava. Seven patients have been operated upon for this anomaly, the first unsuccessful attempt having been reported in 1950.[9] In 4 patients, an attempt was made to anastomose the left atrium or its appendage to the left superior vena cava with subsequent partial or complete obstruction of the left superior vena cava craniad to the anastomosis. In all instances, the patient died as a result either of pulmon [illegible] insufficient flow of blood to maintain systemic arterial p[illegible] that

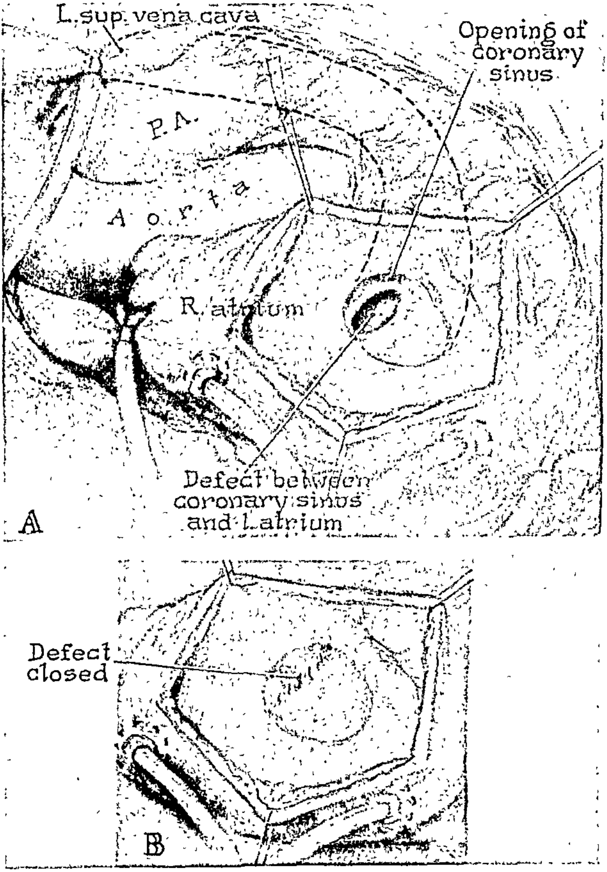

L. sup. vena cava
Opening of coronary sinus
P.A.
Aorta
R. atrium
Defect between coronary sinus and L. atrium
A
Defect closed
B

Fig. 12.—Unusual atrial septal defect between the coronary sinus and the left atrium initially diagnosed as anomaly of the pulmonary venous return. Repair effected by simple suture under direct vision with cardiopulmonary bypass.

the fundamental deficiency in all these operations was an insufficiently large anastomosis to the small left atrium. For this reason, after success in treatment of patients with anomalous drainage into the right superior vena cava, it seemed logical to attempt repair by diversion of the right superior vena cava through the septal defect to the left atrium with ligation of the systemic venous tributaries to the anomalous venous trunk (Fig. 13). This has been attempted in 3 patients, the last being successful.

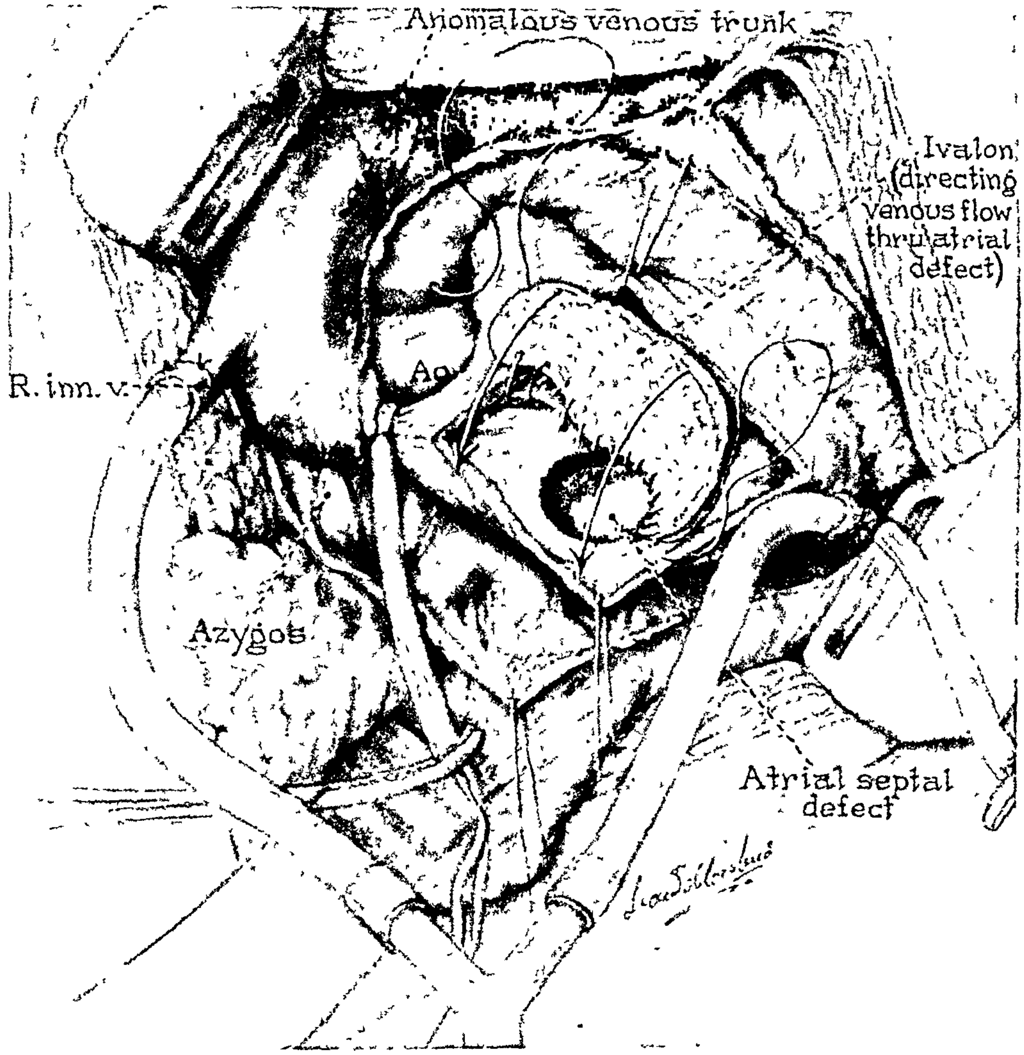


Fig. 13.—Case 35. Total pulmonary drainage to a persistent left superior vena cava. With cardiopulmonary bypass the right superior caval flow was directed by means of an Ivalon patch through the atrial septal defect to the left atrium. The right innominate and azygos veins were interrupted so that pulmonary and left innominate venous blood returned to the left atrium on completion of the repair.

Essentially the same procedure has been attempted in all 3 patients. The first, done with inflow occlusion under hypothermia, failed because of improper suturing in a small infant. The second, no larger, and in severe failure died soon after an operation considerably prolonged because of oozing. Pulmonary edema was transiently present, probably due to overtransfusion. The

third patient was an adult with cardiac enlargement and progressively limited activity Thoracotomy through the fourth right interspace gave good exposure The superior vena cava was cannulated through the right innominate vein, which was later divided, and the inferior cava through the nearby atrial wall Blood from the venae cavae was led through the cardiopulmonary bypass and returned to a femoral artery An Ivalon patch was sutured to direct the superior caval flow, with the entire pulmonary drainage, into the left atrium through the septal defect The azygos vein was ligated, thus leaving only the left innominate vein draining with the common pulmonary trunk to the left He has done well since discharge, has barely perceptible cyanosis, and has had striking reduction in heart size

DISCUSSION

Of the anomalies of the pulmonary venous return, the ones least troublesome in surgical treatment are those in which there is drainage into the right auricle These can be readily handled by methods outlined, simply transposing the veins during repair On the other hand, such anomalies pose a considerable problem to the perfectionist in diagnosis as, with available methods, it is difficult to demonstrate the anomalous connection, sometimes even with external exploration

Although our results in treating patients with anomalous return into the superior vena cava seem to justify continuing with this method of repair, we are not certain that as good or a better method might be the use of a prosthetic material to construct a partition in the superior vena cava[16] This would require a greater period with the heart open and thus require the use of a cardiopulmonary bypass Our reasons for continuing with the method described, in addition to the satisfactory results, have been twofold First, one of the striking features in our experimental use of Ivalon was the scarring and contraction which occurred after the lapse of time This would seem an undesirable feature in this critical area of pulmonary venous drainage, especially in a growing child The second objection has been the greater risk, time involved, and magnitude of the operative procedure when the cardiopulmonary bypass is used as compared with inflow occlusion under hypothermia Simplification of bypass equipment will remove this objection to its use, but we believe that partitioning of the superior vena cava without a prosthesis may still be the method of choice

A number of attempts have been made to treat total drainage into the left superior vena cava, one of the commonest of the total anomalies Only two have been successful[6, 16] Both of these were done with cardiopulmonary bypass and anastomosis of the pulmonary venous trunk to the back of the left atrium through an incision in the right atrium and atrial septum The end result of this method is preferable to the method described here if an adequate anastomosis can be obtained Technically the method described here may be easier Further comparison of the two procedu[illegible]ge, but either is

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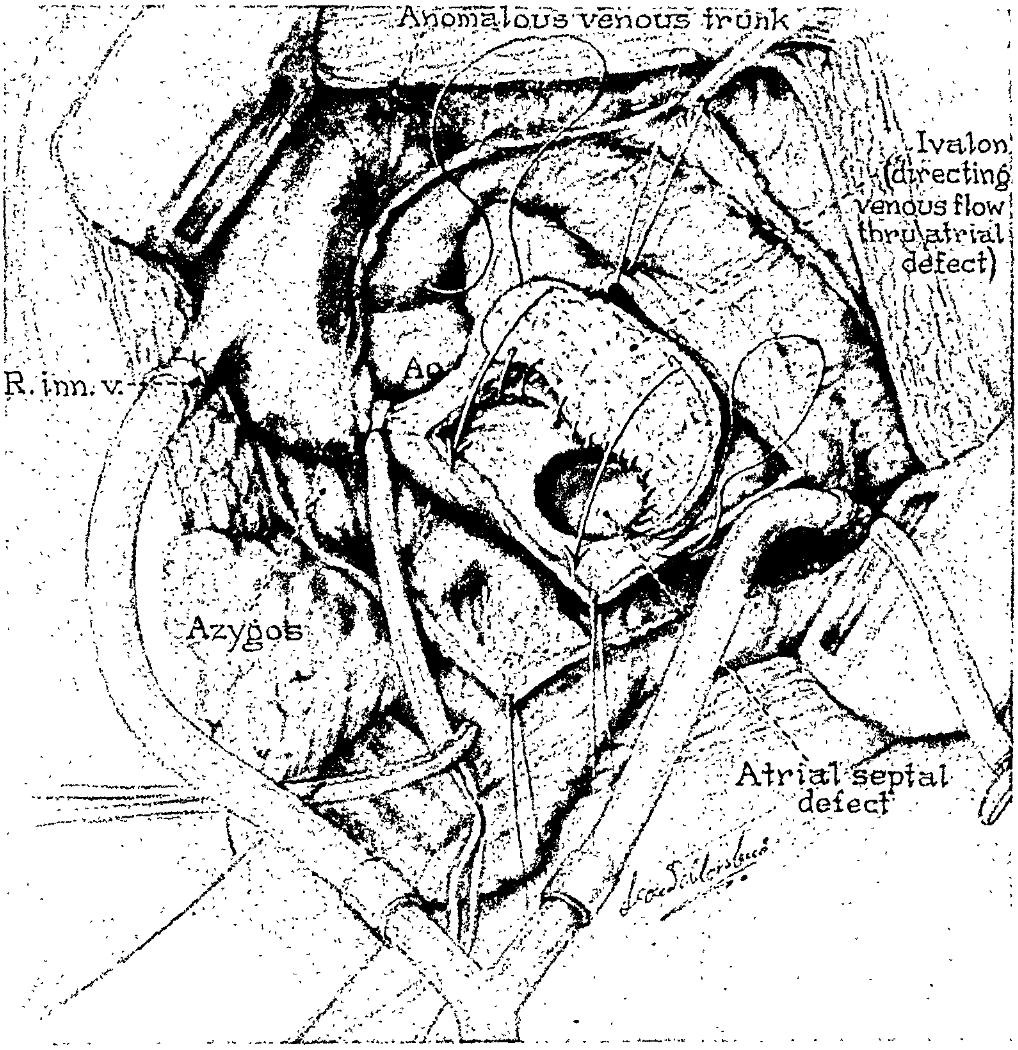

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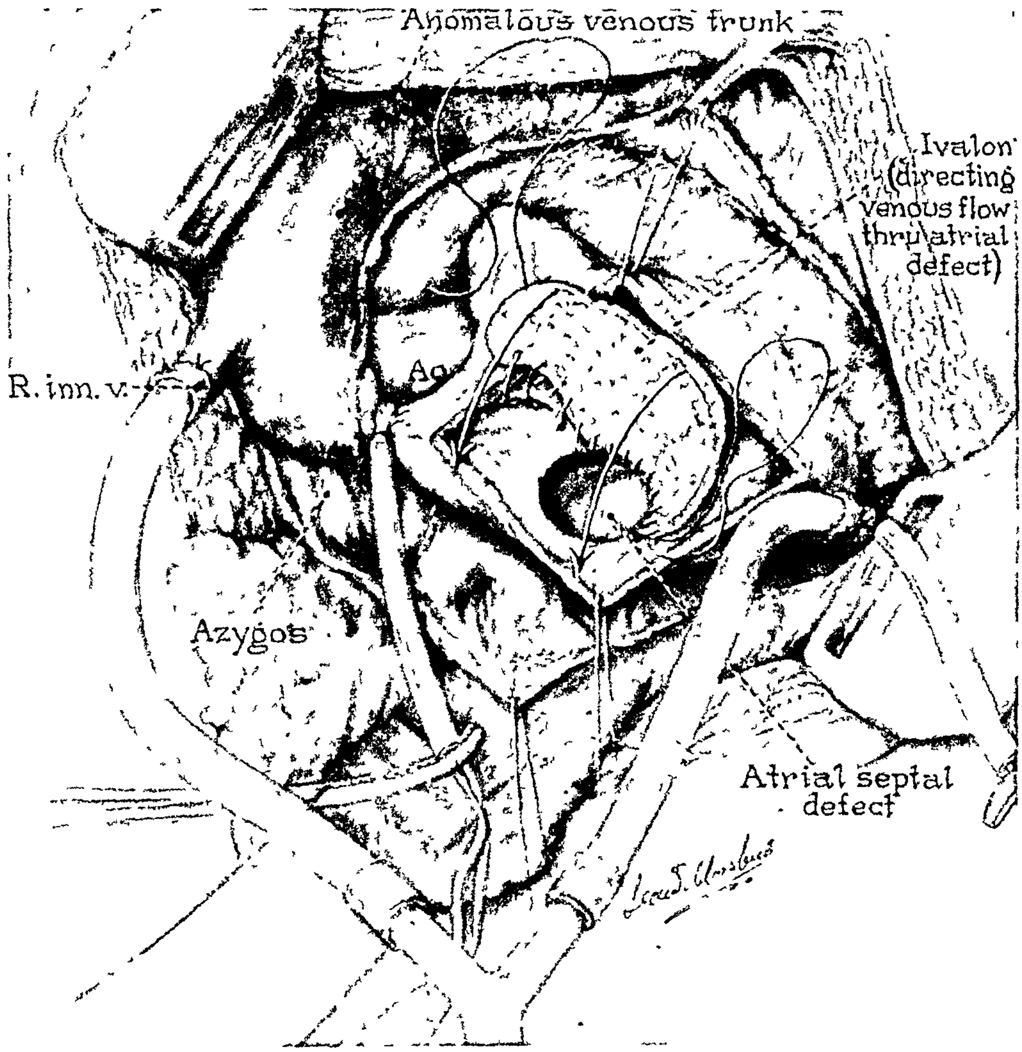

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DISCUSSION

DR ALTON OCHSNER, Jr, Houston Texas—I would like to add briefly to the fine discussion of Dr Spencer the experience we have had in Houston since the pump oxygenator has been available Specifically, I would like to describe the method he referred to for total correction of that anomalous venous return which goes into the systemic system via the left superior vena cava

(slide) This shows the total number of operations for anomalous venous return since we have had the pump oxygenator The group I am most interested in discussing today is the supracardiac group, that is, the pulmonary venous return comes into the systemic venous system above the heart via the left superior vena cava

(slide) The operation that we have performed employs total cardiopulmonary bypass Through a right atriotomy, we have extended the atrial septal defect, and then in the posterior superior to anastomosis of the venous trunk to the left atrial appendage as the waist of the latter is often smaller than the diameter of the venous trunk.[14] Obstruction to pulmonary venous drainage must be prevented at all costs.

Use of moderate hypothermia, inflow occlusion, and coronary perfusion for the repair of atrial septal defects has been satisfactory in our hands and we have not been embarrassed by anomalies of the venous return either unsuspected or diagnosed before operation. We continue to use the technique because of its safety and simplicity, at least for the present, unless we suspect anomalous drainage other than into the right atrium or superior vena cava. For other defects and in infants we prefer the added time for exploration and treatment which cardiopulmonary bypass allows.

SUMMARY

This report concerns 35 cases of anomalous pulmonary venous drainage into the right side of the heart, in 16 of which the pulmonary drainage was totally to the right. This represents 38 per cent of the 92 patients treated during this time because of left-to-right shunt at the atrial level.

Partial anomalous drainage into the right atrium can be readily treated with modification of the techniques used in repair of the simple atrial septal defects. For this, at least for the present, we use hypothermia, inflow occlusion, and suture under direct vision and have been satisfied with the method in treating 10 patients, in one of whom all pulmonary veins entered the right atrium.

When drainage is into the right superior vena cava, the cava has been partitioned to direct the pulmonary venous blood to the left side through the atrial defect which is then closed under direct vision with inflow occlusion and hypothermia. All 11 patients treated by this method have obtained a good result.

Cardiopulmonary bypass has been used in treating successfully 2 patients with total pulmonary drainage into the coronary sinus; one treated under hypothermia died, partly because the correct diagnosis was not made before death. Bypass has been used also to treat 2 patients with total pulmonary drainage into the *left* superior vena cava, the one adult getting a good result. In these two conditions, cardiopulmonary bypass is considered essential to allow adequate time for exploration and treatment, a conclusion supported by poor results with other methods used in earlier cases.

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managing patients in the category, referred to by Dr. Ochsner, in which all the venous return from the lungs goes into the superior vena cava. *As was mentioned, these are very difficult* problems to manage. We have used successfully the technique described by Dr. Spencer in his first 4 patients, anastomosing the common pulmonary venous return to the left auricle It has been said that the left auricle is too small to accept the pulmonary venous return and that this is inherently an unsatisfactory technique. We are not convinced that the technique is necessarily at fault, and we feel that with meticulous attention to details of managing the pulmonary problems, one may achieve a satisfactory result by an extracardiac operation in which the pulmonary venous return is shifted to the left auricle

(slide) We employed this technique in an infant, aged 5 months, whose aortic pressure was 65 mm Hg and peripheral arterial oxygen saturation was 91 per cent. As you can see from the diagram, all venous return drained into the left anterior cardinal vein area At operation we unwisely closed the atrial septal defect first The heart immediately behaved poorly and it was necessary to carry out anastomosis by an extracardiac technique of the pulmonary veins to the left auricle We did not use cardiopulmonary bypass originally during this anastomosis but, because we had to dislocate the heart so strikingly, it was essential to pull off blood from the venae cavae, which were blocked, by turning the heart forward This *permitted a one centimeter anastomosis to the auricle and this infant is now doing well at* 19 months

The point I would like to emphasize is that the loss of many of these patients with *so called pulmonary congestion may be preventable by use of tracheostomy and intensive* efforts at clearing secretions from the tracheobronchial tree Assisted respiration with a mechanical ventilator is also useful at times, this infant had mechanical support of ventilation through a tracheostomy for a week before we considered him out of danger At times during this period, the entire lung field showed severe congestion and patchy atelectasis, except for one upper lobe Without the most intensive care, such patients will die of respiratory inadequacy to which some residual difficulty with pulmonary venous drainage may contribute significantly. Establishment of the connection between pulmonary vein and left auricle by a transatrial approach may be more satisfactory than the extracardiac approach used in our patient, since it may permit a larger anastomosis and also enlargement of the left auricle by internal reconstruction

DR. ROBERT P GLOVER, Philadelphia, Pa—The ingenuity shown by Dr Spencer and Dr Bahnson in the handling of the complicated cases in their series is admirable We have felt that most of the cases encountered in which an atrial septal defect is complicated by anomalous venous drainage can be handled correctly by simple "closed surgical" techniques For the most part, when partial anomalous venous drainage is present, the atrial septal defect is of the "secundum" type Under these circumstances, the septal defect can easily and permanently be closed by the circumferential suture introduced by Sondergaard and further developed by Bjork Re implantation of the venous anomalies, if this proves to be necessary, can also be carried out quite as easily by closed anastomotic methods as by open

Four recent cases exemplify this contention

(slide) In two instances, the venous drainage from the upper and middle lobes on the right entered the right atrium in a common *trunk well below the orifice of the superior vena* cava at a point just opposite the interatrial septal defect. By carrying the encircling suture anterior to this faulty site of entrance into the right atrial wall itself (not as normally in the interatrial groove), the septal defect was tightly closed and the venous return re directed into the left atrium without resort to anastomotic measures One of these patients, as subsequent events proved, should not have been operated upon by any technique, for she died 3 weeks later due to an irreversible pulmonary vascular resistance of high degree.

(slide) In the third case, three veins from the right upper and middle lobes entered the superior vena cava just above the right atrium An ellipse of cava wall was excised containing all three veins and was re implanted into the left atrium with one anastomosis The septal defect was easily closed by tightly tying the previously placed circumferential suture without compromising the lumen of the transplanted vessels The result was excellent.

wall of the right and left atrium we have made a transverse incision into the common venous chamber which lies directly behind the atrium. Here you see the line of incision, here you see the opening.

(slide) Anastomosis is then made between this common venous chamber and the atrium utilizing this opening. Next, the atrial septum is swung to the right of the opening and sutured to the right posterior atrial wall. This enlarges the left atrium and swings the anastomosis into the left atrium. The atriotomy is closed and the final step is permanent ligation of the left superior vena cava.

This has been a very difficult group to repair previously, and this allows total correction of this anomaly at one operation.

(slide) We have seen only 4 cases in which the anomalous drainage was via the left superior vena cava. The first was an adult. The patient developed cardiac arrest when the chest was opened; we were unable to resuscitate him and he died. With the next 3, as you see, we have been successful. We have had 2 infants and one small child. In one, there was transient pulmonary edema, in one there was some pleural effusion. All of them are alive and well today.

DR. J. L. EHRENHAFT, Iowa City, Iowa.—As the experience with open intracardiac surgery increases, an increasing number of sometimes unsuspected associated anomalies are encountered. Our experience up to date with total and partial anomalous venous return consists of 12 patients. Of those, one patient had anomalous venous return of the right lung without an associated interatrial septal defect and one had total anomalous venous return by way of a left superior vena cava. I would like to point out that the approach to and treatment of partial and total anomalous venous return is quite different. Those two anomalies are two different things and should not be confused. Partial anomalous venous return of the right pulmonary veins entering either the superior vena cava or inferior vena cava is very common and is frequently encountered during repair of interatrial septal defects. We would like to show you a very simple method of repair for anomalous pulmonary venous connections of the right lung entering the superior vena cava.

All procedures are done under hypothermia. A modified atrioseptopexy was carried out, shunting the pulmonary venous return and, temporarily, the superior vena caval return through the interatrial septal defect. Next, the superior vena cava was transected between clamps above the entrance of the pulmonary veins into the superior vena cava. The lowermost portion of the superior vena cava was used as a channel for the pulmonary venous return while the upper segment of the transected vena cava was re-implanted into the right atrial appendage. In this manner, both venous streams were separated without obstruction of the superior vena cava or the pulmonary veins. This modification has definite merit in cases where the interatrial septal defect lies extremely high or when the superior vena cava is relatively narrow as it is often in children, preventing a splitting of the superior vena cava as has been demonstrated previously.

We would also like to show you the type of repair carried out on the patient with a total anomalous venous return. This was encountered in a 10-year-old boy. The procedure was carried out under hypothermia. The total anomalous venous return drained into a common posterior venous chamber which connected with the systemic venous return via a left superior vena cava. A large interatrial septal defect was present. The left atrium and left ventricle, even though smaller than normal, were normally developed. Complete correction of this total anomalous venous drainage was accomplished on May 1, 1957. The posterior pulmonary venous chamber was anastomosed to the left atrial appendage with a wide opening. The left superior vena cava was interrupted, diverting all pulmonary venous return through the atrial anastomosis into the left atrium. The interatrial septal defect was closed under direct vision during temporary obstruction of all inflow and outflow tracts of the heart. The patient made an uneventful postoperative recovery and is perfectly normal now.

DR. ROLLINS HANLON, St. Louis, Mo.—I would like to compliment Dr. Spencer on this presentation, which I enjoyed very much. I want to emphasize certain principles in managing patients in the category, referred to by Dr. Ochsner, in which all the venous return from the lungs goes into the superior vena cava. As was mentioned, these are very difficult problems to manage. We have used successfully the technique described by Dr. Spencer in his first 4 patients, anastomosing the common pulmonary venous return to the left auricle. It has been said that the left auricle is too small to accept the pulmonary venous return and *that this is inherently* an unsatisfactory technique. We are not convinced that the technique is necessarily at fault, and we feel that with meticulous attention to details of managing the pulmonary problems, one may achieve a satisfactory result by an extracardiac operation in which the pulmonary venous return is shifted to the left auricle.

(slide) We employed this technique in an infant, aged 5 months, whose aortic pressure was 65 mm Hg and peripheral arterial oxygen saturation was 91 per cent. As you can see from the diagram, all venous return drained into the left anterior cardinal vein area. At operation we unwisely closed the atrial septal defect first. The heart immediately behaved poorly and it was necessary to carry out anastomosis by an extracardiac technique of the pulmonary veins to the left auricle. We did not use cardiopulmonary bypass originally during this anastomosis but, because we had to dislocate the heart so strikingly, it was essential to pull off blood from the venae cavae, which were blocked, by turning the heart forward. This permitted a one centimeter anastomosis to the auricle and this infant is now doing well at 19 months.

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(slide) A fourth case was somewhat similar to the third except that the three veins entering the superior vena cava were well above the right atrium and could not be stretched to the left atrium. A freeze-dried segment of an aortic arch was used to bridge the gap. The largest of the three vessels was anastomosed to the arch itself end-to-end, the next largest vessel to the carotid stump end-to-end, and the third (very small) was simply ligated. The distal end of the graft was then attached to the left atrium, anastomosing the full circumference of the aorta to the incised left atrium. The result was likewise most satisfactory.

Familiarity with the Sondergaard technique and its many possible modifications makes an approach such as described altogether feasible, safe, and satisfactory, without resort to more complicated methods.

DR. SPENCER (Closing).—I have nothing further to say, and I would like to thank the discussers for their interesting comments.

PULMONARY RESECTION IN THE TREATMENT OF TUBERCULOSIS

Experience With 1,730 Patients

Raymond J. Barrett, M.D. (by invitation), Hunter S. Neal, M.D. (by invitation), J. C. Day, M.D., Paul T. Chapman, M.D. (by invitation), Paul V. O'Rourke, M.D., E. J. O'Brien, M.D., and William M. Tuttle, M.D., Detroit, Mich.

THE ADVENT of chemotherapy has brought about profound changes in the trea[illegible] The expansion of [illegible] by these changes, has been so rapid that definition of its limits has become increasingly difficult. The surgeon and his medical colleagues alike have been perplexed by conflicting evidence purporting on the one hand to support its further expansion and on the other to indicate the need for contraction of its scope.

The extensively involved lungs of the very ill often have miraculously survived the initial infection with clearing of reversible components of disease, leaving behind permanently damaged tissue, the removal of which offers the only hope for survival and rehabilitation. At the other end of the spectrum, the antimicrobial agents have been found so successful in the control of lesser amounts of disease that the area where surgery is indicated is not sharply defined.

The accumulated experiences of many individuals and the cooperative studies of the VA-Armed Forces have done much to define the role of resection but many questions remain unanswered. Only by critical appraisal of the results of a significant number of these procedures can any conclusions be reached and some of the questions be answered. That any surgical procedure must be judged by its results, and measured against the hazards involved in its employment, is a truism. When resection is employed in pulmonary tuberculosis, one must be certain that the morbidity and mortality attendant upon it is not excessive and that it offers a good chance for rehabilitation of the patient. Equally important is the obligation to the community to which the patient is returning. The patient must not be a menace to the community or his family because of infectiousness of sputum.

From the Department of Thoracic Surgery, Herman Kiefer Hospital, and the Department of Surgery, Wayne State University College of Medicine, Detroit, Mich.

Read at the Thirty-eighth Annual Meeting of The American Association for Thoracic Surgery at Boston, Mass., May 16-18, 1958.

It is the purpose of this report to present an analysis of our experience with pulmonary resection with particular reference to mortality, morbidity, the incidence of relapse, and the ultimate fate of the patient. With the correlation of various factors such as extent of disease, type of operation, infectiousness of sputum, age, race, and sex, complications, mortality, and the present status of the patients, it is hoped that some helpful information may be obtained.

Perhaps certain disclosures may be forthcoming which will offer some help in defining more clearly the areas where resection can be employed safely and effectively and, more important, the areas where resection should be avoided because of excessively high risk.

HISTORICAL SURVEY

Although sporadic efforts were made to excise portions of lung before the turn of the century following the tragic experience of Block, resections were successfully accomplished by Tuffier in 1891 and Lowson in 1893. However, the first planned lobectomy for tuberculosis was done by Freedlander[1] in 1934. The following remarks concerning early experiences with resection in pulmonary tuberculosis are quoted from Jones'[2] historical review in the John Alexander Monograph Series[2]:

"In 1935, Eloesser and O'Brien each reported a case of one-stage lobectomy for tuberculous cavities; both patients died of a tuberculous spread to the remaining lobes of lung. In 1934, Beye inadvertently but successfully resected the right lower lobe of the lung for a saccular bronchiectasis, which on microscopical study proved to be a tuberculous cavitated lung which had failed to heal following multiple thoracoplasties. The latter patient had a bronchocutaneous fistula when last reported. In 1936, Lindskog had by accident performed a left pneumonectomy on a tuberculous bronchiectatic lung, and a year later the patient was still febrile with fistula, a tuberculous infiltration and active disease with localized empyema. In 1938 Jones and Dolley reported their original series of five resections for tuberculosis, one of a number of small series of tuberculosis resections reported by several surgeons. And finally in 1940, at the meeting of the American Association for Thoracic Surgery in Cleveland, there was a lengthy discussion on the subject, several contributors reporting their own limited series and results. It was obvious at this time that because of the complications of tuberculous infiltration spreads, bronchial fistula, empyema and toxic pleuritis, most surgeons had lost their enthusiasm for resection in tuberculosis. At this meeting the collective series of the several contributors might be summarized in the following fashion: among the resections, there were nineteen cases of tuberculosis treated by total pneumonectomy, only three patients were considered well, six improved, and two were failures. Eight of the nineteen patients were dead, a pneumonectomy mortality of 40.2 percent. At the same time, the various participants in the discussion had a collective series of thirty-one lobectomies for tuberculosis, sixteen patients were classified as well, six as improved, and one as uncertain. There were eight deaths reported, a lobectomy mortality of 20.5 percent. It was significant that in ten of the sixteen patients considered well, tubercle bacilli were not found in the sputum before the lobectomy was performed. The implication, however, need not necessarily be made that these were cases who did not have active tuberculosis, for it is doubtful if any of these patients ever had gastric or sputum cultures and animal inoculations before their surgery."

There followed a period of pessimism and discouragement because of the high incidence of complications and formidable mortality rate. A new impetus was given to resection by the work of Blades and Kent,[3] and the views expressed by Churchill[4] concerning the feasibility of the individual ligation technique, later popularized by Overholt,[5] are now universally accepted and the technique employed.

The last barrier to the successful employment of resection in pulmonary tuberculosis was removed with the discovery of the antituberculosis drugs. During the past decade, resection has been accomplished with increasing frequency and safety and has largely replaced other forms of surgical treatment.

CLINICAL MATERIAL

The statistical data in this report are based upon our experience with pulmonary resection in tuberculosis during the period from Nov. 1, 1949, to Dec. 31, 1957. Since the initial report on the first 202 resections in our series, an additional 1,567 operations have been performed upon 1,528 patients. These original operations are not included in this report except that they appear in the total number of operations.

A brief résumé of the results of the first 202 resections reveals an operative mortality of 6.9 per cent and a late mortality of 5.5 per cent as of the date reported. There were 104 pneumonectomies, of which 19 of the patients are dead (18 per cent), and 98 lobectomies with 6 deaths (6.1 per cent). Bronchopleural fistula occurred in 27, or 13 per cent, of the patients, and was the major cause of death. Spread of disease occurred in 14 per cent of lobectomies and 10.5 per cent of the pneumonectomies. One hundred and seventy-seven patients were living 6 months to 5 years later and 150 (85 per cent) had negative cultures. A follow-up study of this initial group will be the subject of a subsequent report.

TABLE I. COMPOSITION OF ENTIRE SERIES BY AGE, SEX, AND RACE

AGE (YR.)	WHITE MALE (PER CENT)	WHITE FEMALE (PER CENT)	NEGRO MALE (PER CENT)	NEGRO FEMALE (PER CENT)
0-15	0.5	2.5	2.0	4.5
16-29	24.3	46.9	28.6	50.5
30-39	23.7	29.5	24.7	30.8
40-49	26.7	13.9	28.3	10.3
50-59	20.2	6.5	15.5	3.9
60-69	4.1	0.7	0.8	0.0
Total	558	447	254	311

In the group currently being analyzed, there are 1,528 patients on whom 1,567 operations were performed. There were 100 pneumonectomies, 787 lobectomies, 579 segmental resections, and 101 wedge or local excisions. There were 35 bilateral resections and 10 patients had second resections on the same side. In Table I, showing the distribution of patients according to age, sex, and race, it will be noted that the great majority of females, both white and Negro, were under 40 years of age, there being actually 55 per cent of them under 30 years of age. The males are more evenly distributed in the middle and older age groups, 50 per cent of white males being over 40 years of age and almost 25 per cent 50 or over.

Table II, which shows the distribution according to extent of disease, reveals a very striking difference between the white and Negro groups. A very high percentage of both sexes in the Negro group had far-advanced disease. Thus, it is seen that there are four rather distinct groups. The young white females have predominantly moderately advanced disease. The young Negro females have predominantly far-advanced disease. The white males are middle-aged and have predominantly moderately advanced disease, and the Negro males are middle-aged and have far-advanced disease.

TABLE II. TYPE OF DISEASE BY RACE AND SEX

	WHITE MALE (PER CENT)	WHITE FEMALE (PER CENT)	NEGRO MALE (PER CENT)	NEGRO FEMALE (PER CENT)
Primary	0.2	0.2	1.6	1.0
Minimal	7.8	8.1	2.4	4.8
Moderatey advanced	53.0	55.3	37.4	33.0
Far-advanced	39.0	36.4	58.6	61.2

When the present status is related to sex and race, as is shown in Table III, it is seen that the females do far better than the males in both the white and Negro groups, 87 to 89 per cent of them being in the inactive group as contrasted to the white males, only 76.3 per cent of which are inactive, and the Negro males, 82.2 per cent of which are inactive. There are six times as many white males as white females in the active status. More white males are dead than white females. The over-all mortality rate is lowest in white females (2.4 per cent) and highest in Negro males (8.0 per cent). Sixty, or 3.8 per cent, are classified as active, and 1,293, or 82.5 per cent, as inactive. It will be noted that these percentages relate to the total in the series and not just to the survivors.

TABLE III. PRESENT STATUS BY RACE AND SEX

	WHITE		NEGRO		
	MALE	FEMALE	MALE	FEMALE	TOTAL
Active	40 (7.2)	6 (1.2)	8 (3.1)	6 (1.9)	60 (3.8)
Inactive	425 (76.3)	386 (86.7)	206 (82.2)	276 (88.8)	1,293 (82.7)
Dead	33 (5.9)	11 (2.4)	20 (8.0)	11 (3.6)	75 (4.8)
Unknown	60 (10.6)	44 (9.8)	17 (6.8)	18 (5.8)	139 (8.6)

The total mortality figures and present status of activity are found in Table IV, listed according to type of operation. The operative mortality was 2.9 per cent, and the nonoperative mortality was 1.9 per cent, or a total of 4.8 per cent. The former represents any deaths related to operation, however far removed from it, and coincides with hospital deaths. The late deaths were those occurring subsequent to discharge from the hospital, including all deaths from any cause.

TABLE IV. TYPE OF OPERATION VERSUS PRESENT STATUS

	ACTIVE	INACTIVE	DEAD		UNKNOWN	TOTAL
			OPERATIVE	NONOPERATIVE		
Pneumonectomy	4	67	12	4	13	100
Lobectomy	38	633	24	15	77	787
Segmental	15	507	10	8	39	579
Wedge	3	85	0	2	10	101
Total	60	1,293	46	29	139	1,567
Percentages	3.8	82.5	2.9	1.9	8.9	100

An interesting paradox is seen in the pneumonectomy group (Table V), as it relates to the large percentage of Negro females. Whereas they make up only one fifth of the total series, they comprise a third of the pneumonectomy group. They are also conspicuous for the absence of mortality, either operative or late, as contrasted to an extremely high mortality rate in the Negro males (30.7 per cent), and a high mortality rate in both sexes in the white group. This very striking phenomenon is unexplained by any other factor than youth since only 36 per cent of Negro females who had pneumonectomies were beyond the age of 30, as contrasted to 66 per cent of white females, 77 per cent of Negro males, and 93 per cent of white males. Actually, 43 per cent of all white males who had pneumonectomies were beyond the age of 50.

TABLE V. PNEUMONECTOMIES VERSUS RACE AND SEX

	WHITE		NEGRO		TOTAL
	MALE	FEMALE	MALE	FEMALE	
Active	3	0	0	1	4
Inactive	16	16	6	29	67
Dead					
Operative	4 (14.2%)	4 (15.4%)	4 (30.7%)	0	12
Nonoperative	2	1	1	0	4
Unknown	3	5	2	3	13
Total	28	26	13	33	100

TABLE VI. LOBECTOMIES BY RACE AND SEX

	WHITE		NEGRO		TOTAL
	MALE	FEMALE	MALE	FEMALE	
Active	22	5	6	5	38 4.8%
Inactive	176	162	126	169	633 80.5%
Dead					
Operative	12 (4.9%)	2 (1.0%)	8 (5.2%)	2 (1.0%)	24 3.1%
Nonoperative	6 (2.4%)	1 (0.5%)	4 (2.6%)	4 (2.0%)	15 1.8%
Unknown	30	26	10	11	77 9.8%
Total	246	196	154	191	787

When the lobectomies are analyzed by race and sex, a striking difference is apparent between the sexes. The operative mortality in the males is five times that in the females. This again appears to be a function of age. The percentage of lobectomies classified as inactive is 80.5 per cent

TABLE VII. SEGMENTAL RESECTIONS BY RACE AND SEX

	WHITE		NEGRO		TOTAL	
	MALE	FEMALE	MALE	FEMALE		
Active	12	1	2	0	2.6%	15
Inactive	204	171	62	70	87.5%	507
Dead						
Operative	4 (1.6%)	3 (1.6%)	1 (1.4%)	2 (2.6%)	1.7%	10
Nonoperative	5 (2.0%)	0	2 (2.8%)	1 (1.3%)	1.4%	8
Unknown	19	11	5	4	6.8%	39
Total	244	186	72	77		579

TABLE VIII. WEDGE AND SUBSEGMENTAL RESECTION BY RACE AND SEX

	WHITE		NEGRO		TOTAL	
	MALE	FEMALE	MALE	FEMALE		
Active	3	0	0	0	3	3%
Inactive	29	37	12	8	86	86%
Dead						
Operative	0	0	0	0	0	0%
Nonoperative	0	0	0	2	2	2%
Unknown	8	2	0	0	10	10%
Total	40	39	12	10	101	

Both the segmental resections and the wedge and subsegmental group did well as regards operative and late mortality and present status. The operative mortality was 1.7 per cent in segmentectomies and there were no operative deaths in the wedge and subsegmental resections. The percentages appearing in the inactive status in these two groups were 87.5 per cent and 86 per cent, respectively, as would be anticipated.

COMPLICATIONS

The major complications of surgery were analyzed according to infectiousness of sputum in each type of operation. The total incidence of fistulas was 6.2 per cent. In patients with positive sputum, prior to operation, the rate was 11.4 per cent and, in patients with negative sputum, it was 5.1 per cent. This last figure is apparently the minimum incidence attainable under the best conditions in our series, i.e., the negative-sputum status. The incidence of bronchopleural fistula in lobectomy was 5.3 per cent but was three times as high in positive-sputum cases as in negative cases. The highest incidence of fistula was in segmental resections with positive sputum, being 17.8 per cent and somewhat higher than was anticipated, although we were prepared for a higher incidence. Sixty per cent of fistulas in the segmental resections, however, occurred in moderately advanced cases rather than in a preponderance of far-advanced, as we had anticipated in explanation of the figure. Thirty-three of the 50 fistulas in this group, however, were in white males. Thus, two thirds of the bronchopleural fistulas occurred in white males who comprised only 42 per cent of the segmental resections.

The incidence of nontuberculous empyema (bacterial empyema without fistula, predominantly staphylococcic) was 0.6 per cent and spread of disease was equally insignificant as a complication, being 0.7 per cent.

TABLE IX COMPLICATIONS OF SURGERY VERSUS SPUTUM

	SPREAD			EMPYEMA			BRONCHOPLEURAL FISTULA		
Pneumonectomy (100)	63 + 1/63 37 − 2/37	1.6% 5.4%	3%	0 0			4/63 2/37	6.3% 5.4%	6%
Lobectomy (787)	155 + 6/155 632 − 2/632	3.9% 0.3%	1.1%	0 5/632		0.8%	18/155 24/632	11.6% 3.8%	5.3%
Segmental resections (579	56 + 1/56 523 − 0			1/ 56 3/523	1.8% 0.6%	0.7%	10/56 40/523	17.8% 7.6%	8.6%
Wedge resections (101)	7 + 0 94 − 0			0 0			0 1/94	 1.1%	1%
Total	+ 8/ 281 − 4/1,286 12/1,567	2.5% 0.3% 0.7%		1/ 281 8/1,286 9/1,567	0.4% 0.6% 0.6%		32/ 281 66/1,286 98/1,567	11.4% 5.1% 6.2%	

+ Indicates patients positive prior to surgery
− Indicates patients negative prior to surgery

An analysis of the fate of the patients with bronchopleural fistulas the total incidence of which was 6.2 per cent, reveals that this complication is least serious in segmental resections, although still resulting in a formidable 12 per cent mortality rate, as noted in Table X The seriousness of bronchopleural fistula in pneumonectomy is well known Of the six occurring in this series, 3 patients (50 per cent) are dead, and 3 (50 per cent) are active It is also a serious complication in lobectomy, where it resulted in death in 26 per cent of the 42 patients with fistula Its seriousness is also reflected in the 10 per cent, 19 per cent, and 50 per cent active status in segmental resections lobectomies, and pneumonectomies, respectively The over all percentages for the group were 17 per cent active 55 per cent inactive and 20 per cent dead

TABLE X FATE OF BRONCHOPLEURAL FISTULA

98/1,567 = 6.2%		ACTIVE	INACTIVE	DEAD	UNKNOWN
Pneumonectomies (100)	6 BPF	3 (50%)		3 (50%)	
Lobectomies (787)	42 BPF	8 (19%)	19 (45%)	11 (26%	4 (9.5%)
Segmental resections (579)	50 BPF	5 (10%)	36 (72%)	6 (12%)	3 (6%)
Wedge resections (101)	1 BPF	1 (100%)			
Total	99	17/99 17%	55/99 55%	20/99 20%	7/99 7%

RELAPSE

Five of 100 patients with pneumonectomies relapsed 3 of whom were positive prior to operation and 2 negative In the positive group, one third are dead and one third are active while in the negative group, one half are active

There was a total of 51 relapses in 787 lobectomies, a rate of 6.5 per cent The incidence of relapse in the positive cases was 3½ times that in the negative group

The seriousness of relapse in positive patients is emphasized by the fact that in relapses occurring in positive sputum patients, th [illegible] an [illegible] r

TABLE XI. RELAPSE VERSUS SPUTUM AND OPERATION

	WHITE MALE		WHITE FEMALE		NEGRO MALE		NEGRO FEMALE	
100 Pneumonectomies								
	+	−	+	−	+	−	+	−
	18	10	16	10	9	4	20	13
Relapse	2	0	0	0	1	0	0	2
	11%				11%			15.4%
			+ 3/63 = 4.8%			− 2/37 = 5.4%		
Total 5/100 = 5%			1 active 1 inactive 1 dead			1 active 1 inactive		
787 Lobectomies								
	+	−	+	−	+	−	+	−
	60	185	42	153	21	133	32	159
Relapse	14	11	2	7	4	7	3	3
	23.3%	5.9%	4.8%	4.6%	19%	5.2%	9.4%	1.9%
			+ 23/155 = 14.9%			− 28/632 = 4.4%		
Total 51/787 = 6.5%			16 active 5 inactive 2 dead			15 active 11 inactive 2 unknown		

cent mortality and 69 per cent of the patients are still active, as contrasted with no deaths in the negative patients with relapses and 53 per cent still active in the latter group.

In 579 segmental resections, there were 25 relapses with an incidence twelve times as high in the positive as among the negative cases. There is one

TABLE XII. RELAPSE VERSUS SPUTUM VERSUS OPERATION

	WHITE MALE		WHITE FEMALE		NEGRO MALE		NEGRO FEMALE	
579 Segmental Resections								
	+	−	+	−	+	−	+	−
	30	214	10	176	7	65	9	68
Relapses	8	6	2	4	4	1	0	0
	27%	2.8%	20%	2.3%	57%	1.5%	0	0
			+ 14/56 = 25%			− 11/523 = 2.1%		
Total 25/579 = 4.3%			9 active 3 inactive 2 unknown			7 active 2 inactive 1 dead 1 unknown		
101 Wedge Resections								
	+	−	+	−	+	−	+	−
	1	39	5	33	0	12	1	9
Relapses	0	2	0	0	0	0	0	0
	0	5.1%	0	0	0	0	0	0
			Total: 2/101 = 2%; both active					
Summary								
			Pneumonectomy Lobectomy Segmental resections Wedge resections		+ Sputum 14.6% − Sputum 3.3%	Total: 5%		

death (4 per cent mortality in the entire group) and the percentage still active is the same in both groups

There were two relapses in 101 wedge resections, both of which are still active For all types of operation, the relapse incidence was 5 per cent, however, it was over four times as great in the positive sputum cases as in the negative, or 14 6 per cent and 3 3 per cent, respectively

Of the total of 83 relapses, 23 patients are inactive (27 77 per cent), 51 or 63 per cent are active, and 4, or 5 per cent, are dead

CAUSES OF SURGICAL MORTALITY

12 Pneumonectomy Deaths
- 5 Pulmonary insufficiency
- 3 Bronchopleural fistula
- 1 Massive infarct
- 1 Pulmonary edema
- 1 Massive atelectasis of opposite lung
- 1 Immediate postoperative, unexplained

21 Lobectomies
- 7 Bronchopleural fistula
- 3 Transfusion reaction and/or lower nephron syndrome
- 2 Hemorrhage
- 2 Pneumonia
- 1 Empyema
- 1 Pulmonary edema
- 1 Massive embolism to opposite main pulmonary artery
- 1 Cerebrovascular accident
- 1 Wound infection with massive hemorrhage
- 1 Cardiac arrest
- 1 Respiratory insufficiency
- 1 GI hemorrhage 6 weeks postoperatively
- 2 Unexplained

10 Segmental Resections
- 6 Bronchopleural fistula
- 1 Pulmonary insufficiency
- 1 Spread
- 1 Hemorrhage
- 1 Myocardial infarction—clinical impression

The causes of surgical mortality, as listed above, are, for the most part, self explanatory It is noted, however, that the incidence of bronchopleural fistula as a cause of death, although still high, is not nearly so common a cause of death as in the initial series reported Pulmonary insufficiency, which appears as the most frequent cause of death in the pneumonectomy group, would seem to indicate that a considerably larger group of patients is operated upon with marginal functional respiratory reserve

REVIEW OF RESULTS OF OTHER SERIES

There is a striking similarity in the mortality, morbidity, and relapse rates and the present status of patients reported in large individual and collected series

The experience reported by the VA-Armed Forces study group is by far the largest, since it represents the combined results of about 40 participating Veterans Administration hospitals. It is summarized as follows by Raleigh and Steele[6]: There were 5,054 pulmonary resections performed for tuberculosis between 1952 and 1956. The surgical mortality was 15 per cent in 259 pneumonectomies, 3 per cent in 1,800 lobectomies, and 1 per cent in 2,254 segmental resections. Using the incidence of postoperative empyema as an index of surgical morbidity, the morbidity was 17 per cent for pneumonectomy, 4.5 per cent for lobectomy, 4 per cent for segmental resection, and 1 per cent for subsegmental resection. They report that in a small number (18) of pneumonectomies in negative-sputum patients there was no mortality or morbidity. A 10 per cent mortality rate and 20 per cent incidence of empyema was encountered in those patients positive prior to operation. They also note that the mortality rate was almost tripled and the morbidity rate was four times as great in lobectomies in patients with positive sputum as contrasted to those with negative sputum prior to operation.

Gale, Dickie, Rankin, and Curreri[7] report a series of 1,165 consecutively operated cases from 1944 to May, 1954. One hundred and fifty-eight patients were 50 years of age or older at the time of surgery. Thirty-eight were more than 60 years old. There were 36 operative deaths (3.1 per cent); 21 following pneumonectomy, 13 following lobectomy, and 2 following segmental resection. There were 39 (3.3 per cent) nonoperative deaths. Ninety-one per cent, 1,015 of 1,115, were clinically well and inactive. Two per cent are classified as having active tuberculosis.

Robinson, Jones, Meyer, and Reding[8] reported a 12-year experience with 465 resections in which the operative mortality was 2.8 per cent and the late mortality was 2.4 per cent, a total mortality rate of 5.2 per cent. In the long-term, streptomycyin-treated patients, the mortality and complication rates were reduced to 1.7 per cent and 7.6 per cent, respectively, from 16 per cent and 26 per cent, respectively, in the pre-streptomycin period. The follow-up study included only 190 cases (144 lobectomies and 45 pneumonectomies) from the Barlow Sanatorium in which the over-all operative mortality was only 2.1 per cent of 150 patients having resection between 1943 and 1953, inclusive, and followed for 1 to 11 years. One hundred and thirty-one (94 per cent) had negative sputum. Of 104 thoracoplasty patients followed the same length of time, 85 (82 per cent) had negative sputum.

Bickford, Edwards and co-workers[9] reviewed 1,575 operations done from 1947 to April, 1956. There were 27 operative deaths for the full series, a rate of only 1.71 per cent. A 5-year follow-up on the first 399 showed a 2.25 per cent mortality and a 5 per cent fistula rate. Three hundred and forty-seven, or 87 per cent, were clinically well and 29, or 7 per cent, were active or disabled. However, there were only 19 patients over the age of 50 of which 2 died (one had had a segmental resection and one a pneumonectomy) and 4 developed empyema. Reactivation occurred in 14 per cent. The causes of death included 6 due to pulmonary embolism which, in our experience, has been rate. They state that they have taken a more conservative approach to the caseous nodules and excise only those over 2.5 cm. in diameter. They use space reducing thoracoplasty in everything except minor segmental resections.

Hindes and Stegerhock[10] report on 700 resections done between October, 1949, and February, 1954. By February, 1955, 23 of the patients had died, a *mortality of 3.3 per cent. A total of nine tuberculous, and four nonspecific,* empyemas were observed. The number of relapses in a follow-up of 2 to 5 years amounted to 7 per cent. On Feb. 1, 1955, 92 per cent of the patients were well.

Sir Clement Price Thomas[11] reports that in 366 cases, there was a total of 28 deaths, a mortality rate of 7.65 per cent. There were 2 early deaths in 107 lobectomies (1.86 per cent), 4 early deaths in 194 segmental resections (2.06 per cent), and 12 early deaths in 65 pneumonectomies (18.46 per cent). In 85 patients who had open cavitation at the time of operation, 17 died in the hospital, a mortality rate of 20 per cent.

Chamberlain and Klopstock[12] state that in their own original series of 300 segmental resections, reported in 1953 and followed from 1 to 5 years, 93.7 per cent were living and well, 3 per cent were living with disease, and 3 per cent were dead. Nine out of 300 died, 3 (1 per cent) as a result of operation, and 6 (2 per cent) from postoperative complications, or as a result of secondary operations for control of complications. The major complication was bronchopleural fistula in 5.3 per cent. There were 18 exacerbations in the entire series (6 per cent). In an additional 700 patients, they indicate mortality rates and morbidity rates comparable to those in the VA Armed Forces series which are 1 per cent and from 2 to 6 per cent, respectively.

Robinson and Corpe[13] report a series of 119 pneumonectomies which comprised 16 per cent of 746 pulmonary resections done at Battey State Hospital from 1948 to 1957. Almost all patients were operated upon in the face down position and all were connected to water seal drainage for 28 hours, regardless of the absence or presence of thoracoplasty. A concomitant thoracoplasty was done if the patient was in good condition. Ninety seven were performed for "destroyed lung" and 14 for thoracoplasty failure. There were 8 surgical deaths in patients with positive sputum (9.4 per cent) and 2 deaths in patients with negative sputum (6 per cent), the total mortality rate being 8.4 per cent. The tuberculous complications in the group with infectious sputum are listed as 7 bronchopleural fistulas, 8 tuberculous empyemas, 2 of chest wall tuberculosis, 4 spreads, and 19 in which there was disease of the bronchial stump. There were 5 late deaths for an over all mortality of 12.6 per cent.

In a recent communication, Corpe and Blalock[14] have studied a group of patients with persistent cavitation and noninfectious sputum after discharge from the hospital. The relapse rate in 159 patients has been 8.8 per cent. They had been negative for a mean average of nearly 16 months prior to discharge and have been followed for a period of 3 to 48 months (only 26 followed for less than 1 year).

The death rate was 3.8 per cent but they had not had bacteriologic or roentgenographic relapse. In a small group of patients who had refused surgery, 8.3 per cent have had reactivations. Among 38 patients in whom drug therapy was discontinued, there have been no reactivations to date. The authors express considerable optimism as regards this policy and state that the experience serves somewhat to counterbalance their previous concept that these cavities should be removed surgically or collapsed by thoracoplasty prior to the time when the patients could hope to return to their families and earn a living.

The experience of Bell and associates[15] has been at variance with this. In a comparison of the results of medically treated and surgically treated patients with "open-negative" syndrome, they report a relapse rate of 43 per cent in a group of 118 treated medically and a relapse rate of only 8.4 per cent in 153 surgically treated patients. They conclude that pulmonary resection is valuable in improving the over-all results in patients with "open-negative" syndrome.

Cole and Alley[16] present an analysis of 513 patients of which 15 died within 90 days (2.9 per cent), 10 died late (1.9 per cent), and 8 others died apparently unrelated to surgery or tuberculosis, making a total of 4.8 per cent deaths for surgery and tuberculosis, and a 6.4 per cent over-all mortality. Follow-up over 1 to 5½ years indicated good results in 85.4 per cent.

A report of relapses occurring after resection for pulmonary tuberculosis by Hekking[16] showed a relapse rate of 7.4 per cent in 525 cases of resection observed from 2 to 6 years. The conclusion is reached that the relapse rate has decreased since the introduction of pulmonary resection. The chance of development of relapses after pulmonary resections is increased by resection of cavitary processes, by resection in the active stage, and by resection in patients who have shown a low resistance against tuberculosis.

DISCUSSION

Our attitude toward resection over the years has been a conservative one. In general, it can be stated that our indications consist mainly of cavitary lesions and significant caseous nodular residuals, with or without positive sputum, that persist after 6 to 8 months of chemotherapy.

It is obvious that the extent of resection will depend largely upon the distribution of the lesion and other anatomic and technical considerations. When consistent with these limitations, it is our policy to excise the least amount of lung possible with a view to minimal encroachment upon pulmonary function. In the light of this policy, it can be seen that an inevitable consequence has been a steady decrease in the number of pneumonectomies and a sharp increase in the number of segmental and subsegmental resections. The former now represent less than 2 per cent of all resections and the latter accounted for 43 per cent of all resections in 1957.

Although a rather higher incidence of fistulas was encountered in segmental resection, the mortality was not significant enough in relation to other considerations to alter the trend toward its more frequent use. However, when the removal of cavitary lesions with positive sputum is contemplated, even though clearing has occurred in the other segments of a lobe, it is thought unwise to perform segmentectomy because of the danger of transection through disease in the intersegmental plane This applies particularly to the right upper lobe lesions where lobectomy is often preferable

The majority of moderate sized residuals with or without cavity, which are reasonably well localized, present no particular problem It is generally agreed that the indication for resection of these lesions is clear and, indeed, mandatory

The smaller nodular lesions must be assessed on the basis of such factors as age, sex, previous behavior of the lesion, and prior bacteriologic status rather than any arbitrary lower limit of size It is felt that the majority of these small lesions represent dangerous sources of reactivation and that prophylactic resection is indicated The follow up studies of comparable lesions treated medically are far from conclusive as regards the protection afforded against relapse by long term chemotherapy

At the other extreme, in the widely distributed lesions, an aggressive approach is frequently dictated, despite admittedly higher operative hazards when it seems feasible to remove residual areas of disease which appear to be dangerous foci from the standpoint of the probability of subsequent reactivation Such lesions can be operated upon with reasonable safety when respiratory reserve permits When such factors as age, emphysema, poor pulmonary reserve, and general debility combine to increase operative risk significantly a compromise must be made occasionally in favor of prolonged chemotherapy even in the unequivocal open negative lesion When cavity is not definitely discernible by laminagraphy and the above factors obtained the decision will perhaps even more often be made against resection

The unequivocal indication for the employment of surgical excision is the persistence of positive sputum in the face of an adequate trial of chemotherapy It is unfortunate that this group of patients in whom surgery is most urgently needed, suffers the highest complication rate and mortality regardless of the type of resectional procedure employed This is strikingly illustrated by the fact that in the 18 per cent of patients in this report, who had positive sputum immediately ~~prior to operation~~, the mortality rate was 13 per cent, and 13 per cent relapsed This ~~group of patients with positive~~ sputum was responsible for one half of the operative deaths, one half of the relapses, one third of the bronchopleural fistulas, and two thirds of the spreads that occurred in the entire series

In view of the almost certain failure of treatment and grave prognosis of this group without surgery it is felt that these significantly higher morbidity and mortality rates are not excessive and must be accepted and every possible effort made to remove the major residual lesion The control of remaining widely scattered areas of disease must then be entrusted to whatever available drugs may be most effective

The successful management of this difficult problem requires the closest collaboration of the surgeon and his medical colleagues [illegible] significant [illegible]vage rate in this group can be achieved only by careful preoperative assessment of cardiopulmonary capacity, the evaluation of the severity of associated degenerative disease, the manipulation of available drugs to best advantage, the skillful application of surgical techniques and the exercise of good surgical judgment.

Our experience demonstrates that the relapse rate following surgery is not great, being 5.0 per cent for the entire group. However, these patients who relapse have done very poorly, since approximately 70 per cent of them are still active or have died. The over-all experience in our clinic with both medical and surgical relapses is that about two thirds of these recover. The disadvantage which obtains in the surgical case is explainable by the exhaustion of medical and surgical resources in attaining the inactive status in the first place. The control of many of these individuals is a tenuous one at best and often was accomplished with patients who had had extensive chronic disease of long duration. Furthermore, they are often elderly and have had a poor response to chemotherapy for a variety of reasons.

Resectional surgery has proved to be a valuable adjunct to the treatment of pulmonary tuberculosis and has become increasingly safe in conjunction with adequate preliminary treatment with the antituberculosis drugs. Its usefulness in a broad central area where the indications are unequivocal is such as to demand its employment. Its value as insurance against relapse is such that prophylactic resection must be seriously considered even in very small residual lesions. A positive, even aggressive, approach to the problem of the group of patients with extensive disease in whom the prognosis is otherwise grave is believed to be indicated if undertaken with due regard to the limitations imposed by lowered pulmonary function, emphysema, and advanced age.

SUMMARY

A review of our experience with pulmonary resection in the treatment of tuberculosis at Herman Kiefer Hospital has been presented. A total of 1,769 resections has been performed upon 1,730 patients. The current status is known in 91.4 per cent of the patients. The last 1,567 resections have been examined in some detail. The operative mortality was 2.9 per cent and the late mortality 1.9 per cent, a total mortality from all causes of 4.8 per cent. There is still active disease in 3.8 per cent.

The incidence of bronchopleural *fistula* was 6.2 per cent.

Relapse occurred in 83 patients, a total incidence of 5 per cent. Four of these have died, a mortality rate of 4.8 per cent, and 62 per cent still have active disease.

The seriousness of positive sputum at the time of operation is reflected in a significantly higher morbidity and mortality rate. Despite this higher operative hazard, the continued use of resection in this difficult area appears justified.

During the past year, 297 resections have been performed with a total mortality of only 1.3 per cent, or less than half the mortality rate of the entire series.

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(For Discussion, see page 835)

PULMONARY INFARCTION COMPLICATING SEGMENTAL RESECTION

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INTRODUCTION

At the present time, the mortality rate following pulmonary resection in the treatment of tuberculosis is very low indeed—an impressive and highly favorable rate never considered possible a few years ago.[1] Such imposing results, however, are not evident when untoward morbidity and complications following resectional therapy are analyzed. The magnitude of these problems is reflected in the voluminous literature, which has appeared since 1946, dealing with postoperative complications.

Early in 1954, one of us (J. M. S.) was impressed by the gross appearance of a subsegment of pulmonary parenchyma, seen at secondary thoracotomy, which had the gross characteristics of infarcted tissue; this subsegment comprised approximately half of the raw surface of the remaining anterior segment of the right upper lobe following apical and posterior segmental resection of tuberculous residuals 10 days previously. Numerous alveolar air leaks, producing a tension pleural space and prompting the secondary thoracotomy, were visualized over the irreparably devitalized subsegment of lung; an intersegmental vein coursing over the infarcted lung was thrombosed without evidence of proximal ligation; incision into the discolored subsegment produced no bleeding. This necrotic lung tissue was easily removed from the underlying normal subsegment, by traction and blunt dissection, down to the subsegmental bronchus which was divided and closed; no appreciable surface air leaks were then evident, after which a limited modified thoracoplasty was performed, with underwater-seal pleural drainage. Subsequent recovery was uneventful. The pathologic diagnosis was "infarction of lung tissue; no evidence of a specific granulomatous process."

Since becoming aware of this problem of localized postresection infarction of the lung, 399 additional segmental resections have been performed at Fitzsimons Army Hospital. Following these procedures, 14 patients, or 3.8 per cent,

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have developed complications, similar to those related above. Apparently, this pathologic entity has not occurred in the experience of many thoracic surgeons or has progressed to the stage of bronchopleural fistula, empyema, or hemorrhage before secondary corrective surgical measures are undertaken.

During this 4 year period, we have become increasingly familiar with the clinical and roentgenographic characteristics of this postoperative complication, and with the method of management we consider proper when such difficulties arise. Suggestions as to prevention will be presented.

REVIEW OF THE LITERATURE

In regard to the surgical anatomy of the pulmonary vasculature, Appleton,[2] in 1944, was impressed with the degree to which segments of the right upper lobe were supplied by transsegmental arteries. In 22 per cent of 50 cases in his study, the posterior segment was supplied by recurrent branches of the apical segmental arteries. In 8 per cent, the posterior segment was fed in part by branches of the anterior segmental arteries. Similarly, the apical segment received its blood supply partially from rami of the anterior segmental artery. The anterior segment received additional branches from either the apical or the middle lobe arteries in another 8 per cent of specimens. From such findings it may be concluded that the possibility of impairing the anomalous arterial blood supply to an isolated upper lobe segment is not insignificant. In addition Appleton was the first anatomist to relate the pulmonary veins to the intersegmental surface and speculate upon their surgical significance.

Unfortunately, the understanding of the pulmonary vasculature is beset by the difficulty of multiple terminology and various investigators have attempted to improve the situation in different ways. Overholt and co-workers[3] suggested that the venous drainage of the bronchopulmonary segment consisted of lobar veins having both segmental and intersegmental tributaries. Boyden[4] felt that this was oversimplification but surgically significant in dissection of the intersegmental plane.

The technique of segmental resection was gradually perfected after the anatomic concept of the bronchopulmonary segment was advanced. In 1939, Churchill and Belsey[5] reported the employment of this technique in the surgical treatment of bronchiectasis, the underlying aim being to preserve as much normal lung tissue as possible. Clagett and Deterling[6] also adapted this technique to the lingula for the treatment of bronchiectasis. The first significant series of segmental resections in the management of pulmonary tuberculosis was reported by Chamberlain and Klopstock, in 1950. They recorded 72 cases so treated and were encouraged to continue its use, noting that there was a decided decline in the number of postoperative complications as their technical skill and postoperative care improved.

Clagett,[6] appreciating the anatomic concept of the bronchopulmonary segment, applied the "traction" dissection technique, beginning at the hilum, a method, with slight modifications, employed by most thoracic surgeons today.

itially, Clagett infolded the raw surface area, a procedure which apparently l to numerous complications. Overholt left the segmental surface open and owed the lung to "breathe."[3]

Chamberlain and Klopstock cautioned in regard to the dissection of the 't upper lobe hilum noting that there was often an anomalous arterial supply the anterior segment arising from the parent artery to the apical segment as scribed by Appleton and Boyden.[2, 4, 7, 8] They pointed out that ligation of ch vascular structures, before proper identification, might lead to serious com-ications. These investigators also clearly visualized the intersegmental veins receiving tributaries from both sides of the intersegmental plane and advised reful dissection and preservation. Chamberlain and Klopstock also suggested at "it is a good general rule to delay the division of any vein until absolutely cessary."[7]

Most of the experimental work in the pathogenesis of pulmonary infarction s dealt with embolization or ligation of the pulmonary arterial tree. Although farction of pulmonary tissue may occur in the presence of sudden occlusion a large pulmonary artery in a healthy animal, it is not the usual course of ents.[9, 10] It is well established that any condition leading to the production of ·ious venous stasis predisposes to subsequent infarction of arterial origin.

Ameuille and co-workers[11] were concerned with the character of collateral ·culation developing in the presence of pulmonary venous ligation. Only 4 10 dogs survived his intrathoracic procedure and these were sacrificed at tervals up to 7½ months after which injection studies revealed marked vas-larization of the overlying pleural plaque, opposite the operative site, forming llateral venous channels. Such a mechanism of venous return is absent in nonexpanded isolated segment such as occurs in complicated segmental resec-n. In 1938, Reinhoff,[12] in describing a two-stage technique of pneumonectomy r bronchogenic carcinoma, referred briefly to the danger of inadvertently ;ating the superior or inferior pulmonary veins. He suggested this could lead moist gangrene. He cited, however, no specific cases and did not speculate on the pathogenesis. Brantigan,[13] and Kent and Blades,[14] in discussing the atomy of the pulmonary lobes, implied that gangrene might result if the nous drainage of the related lobe was interrupted. In 1948, Swan and Mulli-n[15] did experimental ligation of pulmonary veins in dogs. Pathologic study vealed severe fibrinopurulent pleuritis with vascular adhesions, intense hyper-nia, hemorrhage and edema of the alveoli and bronchioles, and increased sus-ptibility to infection. They noted thrombosis of the veins but did not ob-rve extensive tissue necrosis. They concluded that, in spite of the initial ngestion and alveolar hemorrhage, the lung eventually recovered with ap-oximately a 20 per cent decrease in functional capacity. Perhaps in these periments, the rapidly developing vascular pleural plaques bridged the gap eventing acute lobar pulmonary venous insufficiency. Wyatt and co-workers[16] nducted a similar canine study and noted the importance of antibiotics (peni-lin) in preventing severe postoperative infection predisposing to infarction. ey were impressed with the extent and vascularity of the pleural plaque and mmented upon its significance in establishing collateral circulation. These investigators described small fibrous nodules scattered throughout the healed areas in the pulmonary lobe and speculated upon their pathogenesis without considering them healed infarcts.

In 1951, Stemmermann, Daniels, and Auerbach[17] ascribed the pathogenesis of bronchopleural fistula, following excisional therapy for pulmonary tuberculosis, to pre-existence of disease in the pleural space at the time of surgery. The resultant empyema spread to the bronchial stump with subsequent breakdown and fistulous formation. In 1952, Zelman, Davidson, and Ulmar[18] reviewed 200 cases of pulmonary tuberculosis submitted to surgical resection and found that necrosis of the lingula occurred in 1 case following segmental resection. Steele, Narodick, and Cadden,[19] in 1953, remarked that the disadvantage in the performance of small resections for pulmonary tuberculosis was the high incidence of postoperative complications. Although there was no mortality and the end results were good, 20 per cent of patients developed persistent lung leaks, hemothorax, or empyema. There were, however, no tuberculous complications. In the presence of such leaks, they advocated that it was better to perform a secondary thoracotomy than to persist in the prolonged use of drainage tubes. Bell,[20] in 1955, discussed the postresection space complicating segmental and wedge resection. He reported 61 complications in 308 resections, an incidence of 20 per cent, and noted that the location of the persistent space was usually at the operative site. In his experience, most localized pneumothoraces responded to underwater seal drainage within 2 weeks; a small number, however, became chronic problems with pyogenic infection. He concluded that the occurrence of such complications did not significantly influence the future status of the patient's tuberculosis. *Douglass, Bosworth, Judd, and Chang,*[21] as all of us, had some experience with late leaks or pneumothoraces occurring 2 to 10 days after removal of intrapleural tubes. They used the term "alveolo-pleural fistula" and remarked that a distinction between this problem and bronchopleural fistula should be made. Corpe, Sheck, and Cope[22] in 1956 reviewed 182 segmental resections performed for tuberculosis, and noted that air leaks in the postoperative period accounted for more than half of the total number of complications. Twenty-two patients having pleural spaces required further therapy. Of these, 3 developed bronchopleural fistulas, empyema subsequently developing in 1. Nine of the patients were treated by re-insertion of pleural catheters and 12 by postexcisional thoracoplasty. Final results were considered to be excellent, however, they were unable to make recommendations which might decrease the significant postoperative morbidity rate. In 1955, Findlay, while a member of the Thoracic Surgery Staff at Fitzsimons Army Hospital, became interested in our studies on postoperative pleural space problems and was convinced that postresection pulmonary infarction does occur and, not infrequently, is the sole cause of the residual pleural air pocket which may persist and progress to other complications of a more serious nature, if not promptly and properly treated. In 1956, he reported that a persistent pleural space following partial resection of the lung may lead to bronchopleural fistula months later, and advised early reoperation at which time the visceral pleura is not thickened with fibrosis, and the lung is still expandable.[23] One of us (J. M. S.) reported on some of our early experiences and opinions on "postoperative infarction of the lung" in the Eighth Annual Symposium on Pulmonary Diseases—Fitzsimons Army Hospital, 1955.[24]

CLINICAL FEATURES AND OBSERVATIONS

The complication of pulmonary infarction following segmental resection for pulmonary tuberculosis occurred fifteen times in 400 procedures performed on 371 patients during the period of January, 1954, to February, 1958. This difficulty involved 7 males and 8 females with an average age of 28 years. All except 3 were Caucasian. The average duration of tuberculosis diagnosed prior to surgery was 15.4 months, the longest being 5 years and the shortest 7 months. The period of chemotherapy prior to surgery averaged 7.4 months, the longest course being 15 months, in 3 cases 6 months, and in 1 only 1 month. Chemotherapy primarily consisted of isoniazid, para-aminosalicylic acid and streptomycin in varying combinations. The average duration of negative cultures prior to surgery was 6.8 months, the longest being 12 months and in 1 it was only 3 months. One patient who had never shown positive cultures received 1 month of preoperative chemotherapy.

The surgical description of the adjacent segments remaining at the conclusion of surgery revealed no palpable disease in 8 cases. Five had a definite nodular fibrotic consistency to palpation and 2, upon dissection of the hilum, revealed anomalous vessels. In 9, there was either severe fibrosis obliterating normal tissue planes or nodular disease within the intersegmental plane. In 1 case, a small cavity was opened along the intersegmental plane and this was the patient who exhibited a late tuberculous pseudopulmonary cavity of the type described by Bell and Medlar.[25] Review of the operative reports revealed no technical difficulty in 9 cases although in these patients there was frequent mention of ligation of venous channels and oversewing of leaking segmental surfaces. In the remaining 6 cases, the dissection was described as difficult, requiring sharp procedures and wedging across the intersegmental plane (see Table I).

Pathologically, all specimens obtained at the first procedure revealed cavitary disease except four which consisted, primarily, of healing necrotic foci. Two cavities were considered to be inspissated while three were reported as "healed." In one there was histologic evidence of progressive disease. The tissue removed at the original procedure usually consisted of the apicoposterior segment of the upper lobe, there being seven such procedures on the left and three apical and posterior segmentals on the right. Of the remaining five, two consisted of removal of only the posterior segment of the right upper lobe, the posterior subsegment of the left upper lobe, the apical segment of the right upper lobe and finally a left upper lobe equivalent. When pulmonary infarction complicated the segmental procedure, it always occurred in a segment of which one segmental plane was involved in the dissection procedure. Thus, the anterior segment was the commonest such segment involved, being adjacent and exposed in ten procedures. The three posterior segmental resections subsequently involved subsegments of the apical segment. The 1 case in which apical resection was performed involved a subsegment of the anterior segment and, finally, following removal of the left upper lobe equivalent, infarction occurred in the lingula.

In all cases, the essential features leading to re-operation for presumptive infarction of an adjacent segment or subsegment consisted of a persistent air space, usually apical or "sub-tentorial" (if pleural tent created), and overlying a triangular density with its broad base directed medially and often having a concave upper margin. This apical air space occasionally showed a fluid level; however, none were successfully collapsed by needle or catheter aspiration. Inordinate pain, persisting beyond the immediate postoperative period, was a noticeable feature in one third of the cases. A sharp tearing pain in the affected region was sometimes reported. These patients as compared with others seemed to bleed more profusely in the early postoperative period. Three had hemothoraces treated by lytic agents (streptokinase-streptodornase) prior to removal of intrapleural tubes after initial thoracotomy.

The time which elapsed between initial segmental resection and re-operation averaged 17.6 days in 14 cases. In half of the patients, the second thoracotomy was performed in 9 to 14 days. The longest interval of 144 days occurred in a patient whose initial postoperative course was considered essentially normal. After being released to the Medical Service, there developed a gradually enlarging apical subtentorial air space with the characteristic underlying triangular density. Upon re-operation, a tuberculous pleuropulmonary cavity was demonstrated, this being the only case in which an active tuberculous lesion was proved at secondary thoracotomy. The subsequent course has been uneventful.

In regard to the first operative procedures, pleural space obliterating procedures were performed in 10 cases of which 8 consisted of construction of a pleural tent and in 2 a modified thoracoplasty was performed.[26] In 3 cases partial obliteration of the pulmonary space created after segmental removal was accomplished by pleural margin approximation employing nonsuture cotton ligatures in 2, and interrupted sutures in 1.[29] All patients except 1 received intrathoracic instillation of streptomycin and penicillin.

At re-operation, an apical or subtentorial air space was detected of varying dimensions having an average volume of 100 to 300 c.c. The average space diameter was 5 to 6 cm. In all instances, air leaks could be demonstrated over various areas of the infarcted tissue. Upon stripping fibrinous material from the affected segment, the latter characteristically did not bleed but bubbled diffusely and presented a firm, woody, or soft, frankly necrotic texture to palpation. Its color varied from purplish red to brownish black depending upon the stage and the extent of the necrosis. In 2 cases, there was a frank odor of gangrenous tissue.

The extent of the infarction was variable. It always involved some portion of the intersegmental surface and characteristically involved the most distal

Table I. Infarction Complicating Segment

CASE NO.	AGE, SEX, AND RACE	ADJ. REMAINING SEGMENT*	INTERSEGMENTAL PLANE†	SURGICAL DIFFICULTY‡
1	24 W. M.	Clear	Nodular disease in intersegmental plane	"No difficulty"
2	35 W. F.	Clear	Well-defined	"Intersegmental veins demo strated"
3	15 W. F.	Nodular, anomalous vessels	Fibrotic, ill-defined	"Sharp dissection"
4	31 W. M.	Anomalous blood vessels	Well-defined	No technical difficulty
5	35 W. M.	Clear	Clear	Clamping and ligation of vei in intersegmental plane
6	23 W. M.	Clear	Well-defined	"Ligation of 'distal' puln nary veins of intersegment plane"
7	25 Japanese F	Clear	Well-defined	"Veins draining intersegme tal plane ligated and cut
8	25 Spanish F	Clear	Fibrotic	Clamping and ligation of vei in intersegmental plane
9	20 W. M.	Nodular	Nodular disease in intersegmental plane	Wedging and ligation of "many" intersegmental veins
10	33 W. F.	Nodular	Fibrotic, ill-defined	Wedging across intersegment plane
11	24 N. F.	Nodular	Fibrotic	Sharp dissection required; difficult
12	39 W. F.	Clear	Well-defined	"*Clamping and ligation of* i *tersegmental vessels*"
13	42 W. M.	Clear	Considerable fibrosis at hilum	"Definition of segmental pla accomplished but difficult start"
14	17 W. F.	Nodular	Fibrotic	"Excessive oversewing of i tersegmental vessels"
15	32 W. M.	Nodular	Opened cavity in intersegmental plane	"Wedge across intersegment plane"

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*Description of the adjacent remaining segment in which infarction subsequently occurred.
†Report on the condition of the affected intersegmental plane at the time of the initial surgery.
‡Pertinent difficulties encountered in performance of initial segmental resection.

ECTION FOR PULMONARY TUBERCULOSIS

SEGMENTS REMOVED§	SPACE OCCLUSION‖	SEGMENT INFARCTED	INTERVAL¶ (DAYS)	APPEARANCE AT REOPERATION#
ical and posterior RUL	None	Anterior subsegment RUL	35	Necrotic blood clot, numerous air leaks
ical RUL	Pleural approximation anterior segment to posterior segment	Anterior subsegment RUL	12	Intersegmental veins thrombosed, leaks discernible
terior RUL	None	Apical RUL	9	Numerous small BP fistulas
ical and posterior RUL	Pleural tent	Anterior subsegment RUL	16	Demonstrable surface air leaks
icoposterior LUL	None	Anterior subsegment LUL	10	Localized surface air leaks
icoposterior LUL	Thoracoplasty (modified)	Anterior subsegment LUL	16	No comment by surgeon
sterior RUL	Pleural tent	Apical subsegment RUL	13	Surface air leaks
L equivalent	Pleural tent	Lingula	10	Numerous small BP fistulas
icoposterior LUL	Pleural tent	Anterior segment LUL	22	Air leaks, surgical hemorrhage pulmonary artery
icoposterior LUL	Pleural tent	Anterior subsegment LUL	10	No comment by surgeon
sterior LUL	Pleural approximation anterior segment to superior segment LUL	Apical LUL	10	Localized surface air leaks
ical and posterior RUL	Thoracoplasty (modified)	Anterior segment RUL	14	Foul ordor, visible sutures, hemorrhage from pulmonary artery
icoposterior LUL	Pleural tent	Anterior segment LUL	29	Gangrenous, visible thrombosed vessels
icoposterior LUL	Pleural tent	Anterior subsegment LUL	41	Surface air leaks over infarcted area
icoposterior LUL	Pleural tent, anterior segment to superior segment LLL pleural edges	Anterior subsegment LUL	144	Many sutures in necrotic tissues, 3 air leaks (minute)

§Bronchopulmonary segments removed during the first thoracotomy
‖Concomitant space obliterating procedure performed at the time of initial segmental resection
¶Time which elapsed between the initial segmental resection and reoperation for infarction
#Appearance of the intersegmental surface at the time of reoperation

portion of the specimen; sectioning revealed extension of varying distances into the underlying parenchyma. In 3 cases there was complete infarction of the entire related segment. When surgery was performed under 3 weeks, there was no great technical difficulty encountered in removing the infarcted segment or subsegment; however, there was an exception in 1 case as related below. A fairly clear line of demarcation was usually visible between necrotic and viable lung. Often peripherally the necrotic tissue could be wiped away with a gauze sponge or separated by blunt dissection. The main difficulty in the dissection was encountered at the hilum where, because of close proximity of the pulmonary vessels and the severity of the necrotizing process, serious hemorrhage may ensue, due in 1 of our cases to involvement of the wall of the pulmonary artery by the necrotic process. However, the outcome was entirely successful.

Follow-up studies for periods, ranging from 3 months to 4 years, have revealed no evidence of spread or reactivation in any, and no complications attributable to the second thoracotomy. Additional data pertaining to the 15 patients who had localized postresection infarction of the lung are listed in Table I.

PATHOLOGY

Grossly, the specimens were purplish-black to brownish in color and had a variable consistency. Most presented a firm, indurated, noncrepitant texture but, in some cases, the material was markedly soft and friable. Thrombosis of surface veins buried in blood clot or fibrin along the intersegmental plane was frequently observed. The pleural surface of each specimen was often partially covered by a fibrinous layer having a variable consistency depending upon the time which had elapsed since the previous surgery. This layer was usually soft, friable, and yellowish-white in color. The superficial surface of this plaque was often firmer than the underlying surface where it was in apposition with the necrotic tissue.

The cut surface of specimens usually revealed a dry, finely granular, purplish-black appearance which was sharply demarcated from any comparatively normal lung that may have been included with the specimen. In two specimens in which there was a distinct odor of gangrenous tissue, central softening and liquefaction were observed. Examination of the cut intersegmental surface often revealed thrombosed vascular structures leading into the necrotic lung.

Microscopic examination of sections taken at right angles to the segmental surface revealed characteristic hemorrhagic infarction with focal necrosis of pulmonary tissue tending to become confluent at the surface. The central portions of these lesions showed complete loss of cytologic detail including the nuclei of alveoloseptal cells. In spite of such profound necrosis, the tissue characteristically maintained its configuration with well-defined acidophilic hyaline walls inclosing degenerating masses of conglutinated red blood cells. Although occasionally the periphery of the infarcted area was well circumscribed by fibrous tissue (probably representing a sublobular fibrous tissue plane), it was more characteristic to find no such delimitation, the zone between viable and nonviable tissue being remarkably free of either fibroblastic tissue or inflammatory cells. Healing was evidenced by a feeble and ineffective organization of intra-alveolar fibrin resulting in thick walled avascular nonfunctional alveoli.

The contained vessels showed thromboses and mural necrosis, particularly noticeable in the superficial intersegmental veins. Serial sections of the latter revealed proximal viability and luminal patency. Spaces within necrotic tissue were often observed, this was felt to be histologic representation of the multiple alveolopleural fistulas so characteristic of these lesions.

Three aspects of this material appeared particularly interesting to one of us (H. N. H.). Elastic stains upon necrotic tissue showed a surprisingly intact architecture despite the profound necrosis, and the prolonged interval following initial surgery. The necrotic tissue tended to become hyalinized and except for 2 cases there was little evidence of actual lysis of tissue. The second puzzling feature of these specimens consisted of a marked degree of endothelial proliferation and, often, luminal obliteration of related arterial structures. These were often observed in adjacent viable pulmonary tissue. The endothelial proliferation might be interpreted on the basis of adjacent tuberculous disease, however, the presence of an organizing thrombus would tend to discount this possibility. The final impressive feature was the degree to which metaplastic bronchial squamous epithelium was disrupted and dispersed among the peripheral layers of necrotic tissue.

BACTERIOLOGY

It is not surprising that infection did occur in 3 of the 15 cases. Such infections were confined to the infarcted segment, subsegment, or pleuropulmonary cavity. In 2 cases (12, 13, see Table I) there was frank gangrenous tissue, due presumably to a Vincent type infection, although cultures were sterile. The final case (15) was the only 1 showing evidence of an active tuberculous process in tissue removed at the second thoracotomy. The patient had a prolonged delay of 144 days before secondary thoracotomy and acid fast bacilli were demonstrated on smear and tissue stains in the wall of the cavity, however, cultures were negative. In this instance, there was formation of a tuberculous pleuropulmonary cavity.

CASE REPORTS

Three clinical cases which illustrate this postresection syndrome of localized pulmonary infarction are presented below. The other 12 cases were rather uniformly similar to those here recorded, thus, an accurate preoperative diagnosis was made in our last 8 patients.

Case 2.—A 35 year old white woman was admitted on April 9, 1954, with a diagnosis of pulmonary tuberculosis. Numerous roentgenograms, since 1951, revealed a nodular infiltrate confined to the area of the right upper lobe which was considered to have undergone no change. However, in February, 1954, two routine gastric cultures were positive for acid fast bacilli. Other laboratory studies and physical examination revealed nothing remarkable other than post tussic rales over the right upper chest. Chemotherapy consisted of streptomycin and isoniazid. On Oct. 22, 1954, after 6 months of chemotherapy, a right upper lobe apical segmental resection was performed for significant residual nodular disease restricted to this segment. The created raw surfaces of the anterior and posterior segments were approximated at the pleural margin by four interrupted sutures. Twelve days after initial surgery, a thoracotomy was again performed because of a persistent air-fluid space which had not responded to multiple thoracenteses (Fig. 1). The midpectoral subsegment of the anterior segment appeared to be infarcted, having a dense, rubbery consistency, and the vessels along the segmental plane were thrombosed; intermittently, air bubbled from this surface. The involved subsegment was removed without difficulty after which the raw segmental surfaces came into favorable apposition as the lung was expanded by the anesthesiologist; the pulmonary remnant filled the hemithoracic space completely. Two large tube pleural drains were connected to water-seal bottles and suction instituted. Subsequent recovery was uneventful and the patient has continued to do well (Fig. 2).

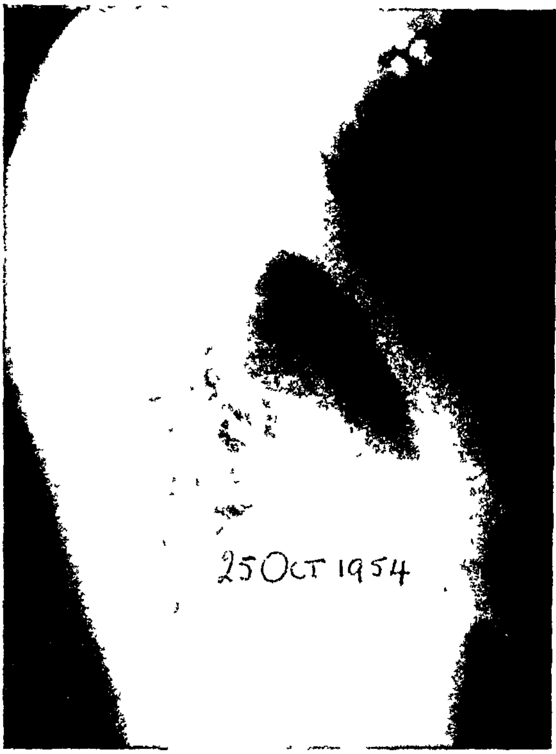

Fig. 1.

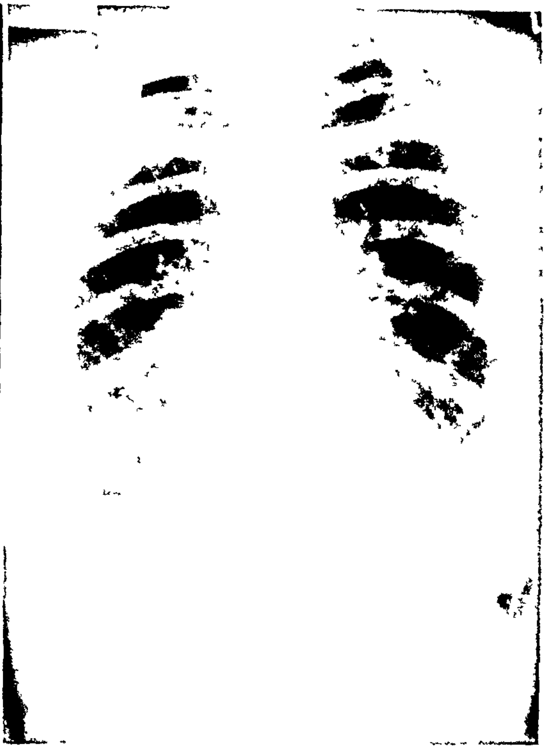

Fig. 2.

Fig. 1.—Right lateral roentgenogram of chest of Case 2 showing postoperative air-fluid space at site of apical segmental resection. Triangular density anterior to space proved to be infarction of subsegment of the anterior segment.

Fig. 2.—Roentgenogram of chest 20 months later. Regenerated fifth rib on right. Patient asymptomatic.

Pathologic examination of the first specimen revealed caseonodose tuberculosis. The second specimen consisted of organizing hemorrhagic infarction of the anterior subsegment with nonspecific chronic pleuritis and pulmonary fibrosis.

Case 5.—This 35-year-old white man was admitted on April 18, 1956, because of an expanding, rather circumscribed lesion in the left upper lobe (Fig. 3). Skin tests: PPD No. 1, four plus; histoplasmin and coccidioidin, negative. No positive smears or cultures for acid-fast bacilli were obtained. Streptomycin and isoniazid were started on May 18, 1956, and apicoposterior resection was performed June 8. The solitary lesion, 2.2 cm. in diameter, proved to be a rather thick-walled tuberculous cavity from which acid-fast bacilli were isolated.

No concomitant collapse procedure was performed. In the postoperative period, the water-seal suction bottles continued to bubble and an apical air space failed to improve (Fig. 4). He continued to complain of rather severe chest pain. Ten days after segmental resection, he was returned to surgery and an infarction of a subsegment of the anterior segment, from which air leaked freely, was demonstrated and removed. A modified thoracoplasty was performed and the patient has done well since.

CASE 13.—A 42-year-old white man noticed the onset of fatigue 2 years prior to admission. A chest roentgenogram on July 31, 1956, revealed bilateral upper lobe cavitation. The only early positive culture was obtained as the result of bronchial washings. Chemotherapy was instituted on Aug. 8, 1956, with 600 mg. of isoniazid and para-aminosalicylic acid, 12 grams daily. On December 17, the isoniazid was increased to 900 mg. On March 15, 1957, a right thoracotomy was performed with removal of the apical and posterior segments. A tent of the apical parietal pleura was performed and recovery was uneventful. On March 28, 1957, sputum culture was again positive for acid-fast bacilli and the isoniazid was increased to 1,500 mg. with 1 gram of streptomycin daily. On July 10, 1957, an apicoposterior resection of the left upper lobe was performed. Postoperative x-ray studies revealed well-expanded lung with some cloudiness over the apex without discernible space. On July 14, the intercostal tubes were removed. However, on July 26, 1957 (Fig. 5), an air space was observed at the apex and it was felt that this had resulted from an infarcted segment. Air leak was continuous as demonstrated by needle aspiration. He complained of almost constant "sharp tearing" chest pain. Twenty-nine days following the initial left thoracotomy, the left thoracic cavity was entered through the previous operative site; pleural symphysis was observed over an extensive area, and incomplete infarction of the anterior segment was seen

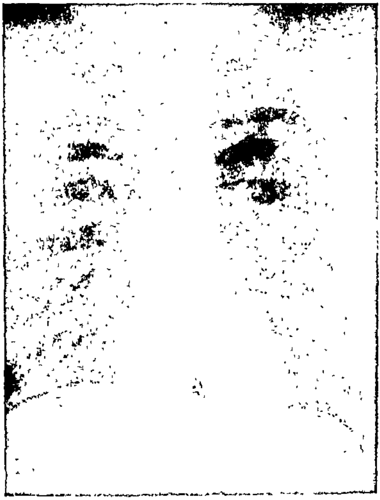

Fig. 3.

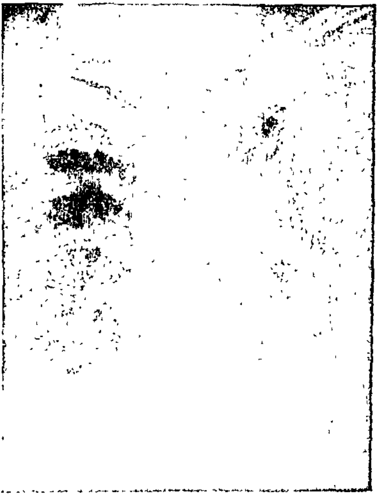

Fig. 4.

Fig. 3.—Roentgenogram of chest, Case 5, prior to resection of solitary tuberculous lesion in apicoposterior segment.

Fig. 4.—Roentgenogram 8 days after segmental resection. The large tension apical pleural space is demonstrated. Infarction in anterior segment produced the triangular dense shadow below the space.

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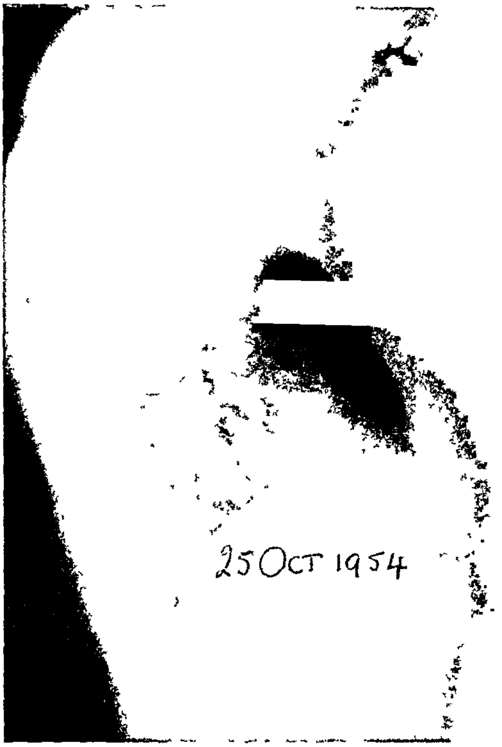
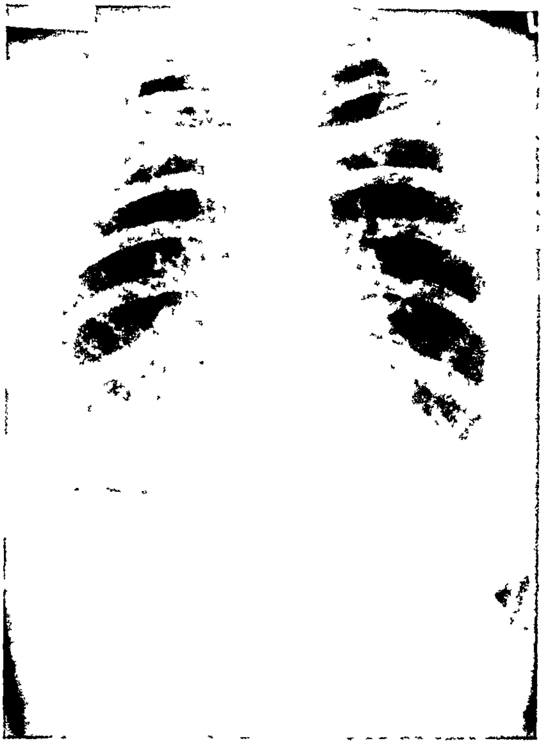


Fig 1.



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which had advanced to the stage of gangrene in one area. Small air leaks on the surface of this infarcted segment were observed and thrombosed vessels leading to the anterior segment were palpated and visualized. Segmental resection of the infarcted segment was accomplished and a modified thoracoplasty was performed. Subsequent course has been completely uncomplicated (Fig. 6). The pathologic specimen consisted of the anterior segment showing a large area of infarction (Fig. 7).

DISCUSSION

Pulmonary infarction complicating segmental resection, according to our concepts, is certainly not a new entity. The characteristic symptomatology has long been recognized, but the underlying pathogenesis has not. Such terms as the "late space problem," "alveolo-pleural fistula,"[1] "masked broncho-pleural fistula,"[7] "occult broncho-pleural fistula"[1] have been offered in an effort to characterize this problem or its complications. The salient clinical findings and basic diagnostic features are: (1) a persistent tension air space in the region of the previous pulmonary resection, (2) no evidence of an overt bronchopleural fistula, and (3) commonly demonstrated roentgenographically, below the pleural space, is a triangular density with its broad base directed medially and having a concave upper margin if no fluid is present, otherwise a horizontal air-fluid level.

The complications which may accompany or follow such pulmonary infarctions, if not corrected by early and proper surgical measures are as follows: (1) A persistent and nonresolving air space, provided the resulting pulmonary infarction is of significant depth and magnitude. Such may negate the intended purpose of segmental resection, i.e., the preservation of uninvolved and apparently normal functioning pulmonary segments; thus, the space plus the fixed necrotizing and/or organizing segment will deter adjacent segments from expanding to full functional capacity. (2) Bacterial infections—blood serum, avascular tissue, and the 'dead space' provide an excellent culture media for bacterial growth; the intermittent ingress of respired air via the porous necrotic segmental surface is a factor worthy of mention. With due deference to antimicrobial agents, nevertheless, we must assume that, in due course of time some untoward superimposed complication of a bacterial nature will ensue. A listing of such possibilities is proposed as follows: localized empyema, mixed empyema (pyogenic and tuberculous), tuberculous pseudopulmonary cavity, adjacent specific or nonspecific pneumonitis, contiguous tuberculous reactivation and/or distant spread, putrid lung abscess (such has been observed in our experience on one occasion, however the exact nature of the pathogenesis was not determined), osteomyelitis of ribs and chest wall infection. (3) Frank and indisputable bronchopleural fistula. (4) Massive fatal pulmonary hemorrhage—such has been reported in the literature following segmental and subsegmental resection.

The prevention of this type of postoperative complication, i.e., localized pulmonary infarction, depends to a large degree upon maintaining the integrity and continued patency of the remaining branches of the intersegmental vein. It is evident, when considering Column 3 data in Table I (Surgical Difficulty), that the crux of the problem appears to be the surgically exposed surface venous

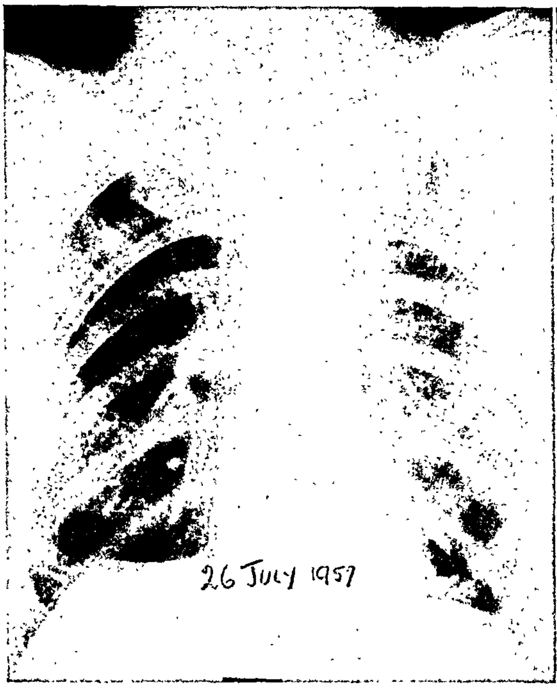

Fig. 5.

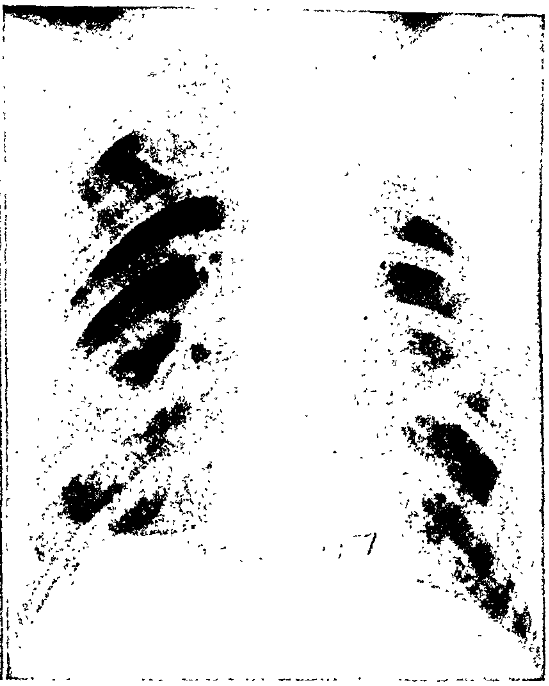

Fig. 6.

Fig. 5.—Roentgenogram of Patient 13 taken 16 days after apicoposterior resection on the left where dense, roughly triangular shadow is demonstrated below apical space. Good contralateral expansion is noted 4½ months after apical and posterior segmental resection and utilization of a pleural tent on right.

Fig. 6.—Roentgenogram of chest 2½ months after second thoracotomy and concomitant upper stage modified thoracoplasty, left, in management of postresection infarction in the anterior segment.

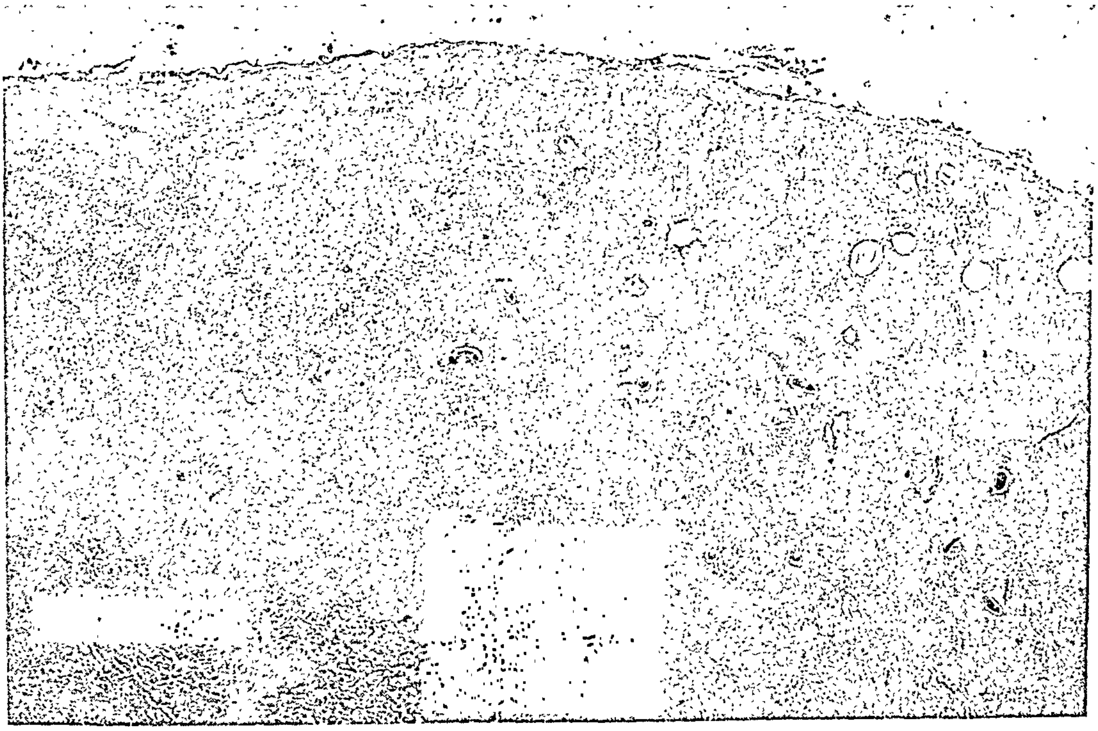

Fig. 7.—Microscopic appearance of hemorrhagic pulmonary infarction (Patient 13), showing characteristic focal necrosis, air spaces, and vascular thromboses. Compressed alveoli and poor delineation left lower area.

which had advanced to the stage of gangrene in one area. Small air leaks on the surface of this infarcted segment were observed and thrombosed vessels leading to the anterior segment were palpated and visualized. Segmental resection of the infarcted segment was accomplished and a modified thoracoplasty was performed. Subsequent course has been completely uncomplicated (Fig. 6). The pathologic specimen consisted of the anterior segment showing a large area of infarction (Fig. 7).

DISCUSSION

Pulmonary infarction complicating segmental resection, according to our concepts, is certainly not a new entity. The characteristic symptomatology has long been recognized, but the underlying pathogensis has not. Such terms as the "late space problem," "alveolo-pleural fistula,"[21] "masked broncho-pleural fistula,"[27] "occult broncho-pleural fistula"[21] have been offered in an effort to characterize this problem or its complications. The salient clinical findings and basic diagnostic features are: (1) a persistent tension air space in the region of the previous pulmonary resection, (2) no evidence of an overt bronchopleural fistula, and (3) commonly demonstrated roentgenographically, below the pleural space, is a triangular density with its broad base directed medially and having a concave upper margin if no fluid is present, otherwise, a horizontal air-fluid level.

The complications which may accompany or follow such pulmonary infarctions, if not corrected by early and proper surgical measures, are as follows: (1) A persistent and nonresolving air space, provided the resulting pulmonary infarction is of significant depth and magnitude. Such may negate the intended purpose of segmental resection, i.e., the preservation of uninvolved and apparently normal functioning pulmonary segments, thus, the space plus the fixed necrotizing and/or organizing segment will deter adjacent segments from expanding to full functional capacity. (2) Bacterial infections—blood, serum, avascular tissue, and the "dead space" provide an excellent culture media for bacterial growth, the intermittent ingress of respired air via the porous necrotic segmental surface is a factor worthy of mention. With due deference to antimicrobial agents, nevertheless, we must assume that, in due course of time, some untoward superimposed complication of a bacterial nature will ensue. A listing of such possibilities is proposed as follows: localized empyema, mixed empyema (pyogenic and tuberculous), tuberculous pseudopulmonary cavity, adjacent specific or nonspecific pneumonitis, contiguous tuberculous reactivation and/or distant spread, putrid lung abscess (such has been observed in our experience on one occasion, however, the exact nature of the pathogenesis was not determined), osteomyelitis of ribs, and chest wall infection. (3) Frank and indisputable bronchopleural fistula. (4) Massive fatal pulmonary hemorrhage—such has been reported in the literature following segmental and subsegmental resection.

The prevention of this type of postoperative complication, i.e., localized pulmonary infarction, depends to a large degree upon maintaining the integrity and continued patency of the remaining branches of the intersegmental vein. It is evident, when considering Column 3 data in Table I (Surgical Difficulty), that the crux of the problem appears to be the surgically exposed surface venous channels, which, no doubt, play an important role during the immediate postoperative healing phase. It is noteworthy, that the surgeons reported various types and degrees of difficulties in 12 of the 15 patients during dissection in the intersegmental plane. Thus, many factors influence the postoperative competence of the intersegmental pulmonary veins. Some factors which immediately come to mind are: active or fibrotic tuberculous residuals involving the intersegmental plane; tuberculous nodules beyond the intersegmental boundary which are removed by additional wedge excision; excessive bleeding from intersegmental plane, requiring clamping, ligatures and sutures; excessive air leaks, the control of which may also require clamping, ligatures and sutures with possible inclusion of venous tributaries; rare anomalous venous distributions; and technical errors and difficulties. It might be noted that nine surgeons performed the initial surgery on the 15 patients developing this complication; two being staff surgeons and seven were residents on the Thoracic Surgery Service—all being capable of operating independently or had staff surgeon assistance and supervision.

An additional factor which seems to warrant consideration is the possible prophylactic value of the surgically created pleural tent. We feel such a procedure may be of some value if the pulmonary surgical defect is relatively flat (not a deep "wedge like" defect); thus, the pleural tent seems more commonly indicated after an upper lobectomy than following segmental resection. The prevention of this postoperative complication may depend also upon the degree of early angioplasia and venous channels which form in the fibrinous plaque separating the remaining segment from the adjacent pleural space. If there is rapid organization of this surface plaque, then minimally infarcted zones will probably be effectively walled off and healing will take place. On the other hand, if early angioplasia and fibroblastic proliferation is poor, the necrotic surface will continue to leak via multiple alveolopleural fistulas.

This early fibrinous plaque covering the raw surface is uniformly demonstrated in the experimental animal as well as in patients having had pulmonary resections and is a major contributing reparative process which makes the technique of segmental resection possible. This consideration should always be kept in mind by the surgeon who, in some instances, may elect to enhance this aspect of the surface healing process by performing a pleural tent or a limited modified upper-stage thoracoplasty. We have shown to our satisfaction on numerous occasions, after performing pulmonary dissection techniques on dogs, that the rapidly forming fibrinous pleural plaques make it extremely difficult to produce alveolar air leaks of sufficient duration to produce pleural air spaces, although we rather uniformly establish areas of subsegmental infarction by ligation of intersegmental veins.[28]

CONCLUSIONS AND RECOMMENDATIONS

It seems superfluous to state that surgical skill, judgment, and experience are all important, nevertheless we are convinced that any thoracic surgeon, regardless of experience and training, may from time to time be confronted with this postoperative complication Therefore, it seems imperative that all should keep this syndrome in mind when postresection space problems occur It is very questionable if it is proper to apply conservative methods of management such as multiple thoracenteses and re insertion of catheters and tubes for lengthy periods Most of our patients have been given the benefit of such methods of early management without any evidence of success Accordingly, *it is proposed that if such methods fail in 4 to 6 days that secondary thoracotomy is in order* Re inserted closed drainage tubes should not remain long enough to initiate or contribute to secondary infection It is our opinion that secondary thoracoplasty alone would be curative in only a small percentage of cases, however, such a procedure of the modified type or construction of an apical parietal pleural tent concomitantly with secondary thoracotomy will not infrequently be necessary

At this juncture of our incomplete understanding of this problem of post segmental infarction of the lung, we hesitate to make any concrete or dogmatic recommendations and proposals other than those related above Nevertheless, a "scheme of surgical conduct" is offered which we believe is sound in principle as based upon our clinical experience and incompleted laboratory investigation of this problem to date"[8]

Recommended "Scheme of Surgical Conduct"—

1 Maintain integrity of branches of intersegmental vein on surface of retained segment Segmental surface clamping ligatures, and stitch sutures are kept to a minimum, hemostasis is often surprisingly complete after complete expansion of the segment by the anesthesiologist, meticulous and gentle dissection in the intersegmental plane is mandatory

2 Do not attempt suture infolding of raw segmental surface

3 Do not attempt reconstitution of pulmonary remnant by multiple layer sutures beginning in the depth of the postresection defect, such closure technique would seem to contribute to intersegmental venous stasis, thrombosis, and subsequent infarction

4 Complete removal of segment peripherally is essential, dissection may easily progress outside the intersegmental plane, leaving a "nubbin" of subsegment quite devoid of circulation, although expansion may be surprisingly good

5 Perform upper lobectomy on the right in favor of apical and posterior segmental resections planned, i e , if fibrosis and nodular disease are found to involve the apical and anterior intersegmental plane Pleural tent or limited modified thoracoplasty may seem indicated

6 A similar situation on the left, as related in 5 above, with apicoposterior resection contemplated—if intersegmental fibrosis not overly extensive—suggest that anterior segment be retained, and manage infarction of anterior segment by secondary thoracotomy if such should develop

7. Secondary thoracotomy in 10 to 14 days when there is clinical and roentgenographic evidence of postoperative pulmonary infarction. Surgical judgment will dictate if concomitant pleural tent or modified thoracoplasty should be performed.

SUMMARY

A series of 15 patients, having incurred pulmonary subsegmental or segmental infarction following segmental resection for tuberculosis in 400 consecutive procedures, has been analyzed. Clinical and roentgenographic features characterizing this postoperative complication are presented. The proposed pathogenesis of demonstrated infarcted contiguous segments and pathologic findings are discussed, and recommendations are offered in regard to prevention. Once frank pulmonary infarction occurs, secondary thoracotomy in 10 to 14 days is recommended. All 15 patients having had secondary thoracotomy are without evidence of reactivation and doing well 3 months to 4 years after segmental resection. The mortality to date in this series of 400 pulmonary segmental resections is 0.5 per cent; 1 patient having died of cardiac arrest at completion of pulmonary resection and the other of pulmonary hemorrhage 6 weeks after upper lobectomy and superior segmental resection.

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Discussion

(Papers by Barrett [page 803] and Salyer [page 818] and Their Associates)

DR ROBERT KLOPSTOCK, Brooklyn, N Y —The Veterans Administration and Armed Forces Study Group is reporting experiences year after year in series of even larger figures But there are just as many cases of resection performed as the definitive form of therapy for pulmonary tuberculosis, which are not reported These significant figures themselves represent the efficacy of the resectional therapy for pulmonary tuberculosis

The majority of thoracic surgeons of the younger generation hardly know any other type of surgical management of pulmonary tuberculosis except resection The young thoracic surgeon is so exceptionally well trained in pulmonary surgery today because tuberculosis of the lung can be treated by surgical excision with a high degree of safety and thus yield a great volume of suitable surgical cases

As this Association meets in Boston this year it is perhaps proper to remind the younger generation of chest surgeons present that both the intellectual and surgical conception of the primary elective and limited resection as the surgical therapy of pulmonary tuberculosis emanated from this city's Massachusetts General Hospital Dr Churchill and Dr Belsey designated the pulmonary segment as the surgical unit of the lung in 1939[1] At the Boston meeting of the American College of Surgeons in 1941 this hospital displayed an exhibit[2] on the surgical pathology of the lung demostrating that the distribution of the chronic suppurative diseases of the lung were restricted to the bronchopulmonary unit with characteristic segmental predilection for each disease including tuberculosis In 1943, 15 years ago this month, another study entitled "Lobectomy for Pulmonary Tuberculosis,"[3] proposed the primary and elective resection of the stabilized and irreversible necrotic pathology produced by tuberculosis process in the lung In this report, the cases of 6 consecutive patients successfully operated upon were presented exhibiting the variety of the patterns and stages in which tuberculosis of the lung is manifested in man Opposition to this proposal was raised and it is recorded

The introduction and general use of specific antimicrobials in the treatment of pulmonary tuberculosis gave us the pharmacologic tool to localize and reduce the tuberculous process in the lung to its irreversible necrotic component within a short time and almost at will This was a tremendous achievement, but it could be exploited and secured only because the conception and the necessary refined surgical methods for the primary and selective resection of the residual irreversible and potentially dangerous lesions were already at hand, thanks to the scientific vision of Edward Churchill of this city, at the Massachusetts General Hospital. The rest of the story is being carried out by thoracic surgeons all over the world, among whom is the eminent essayist to whom we have just listened.

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DR. WATTS R. WEBB, Jackson Miss.—I enjoyed very much the discussion given by Dr. Barrett on the trends in the therapy of tuberculosis. In reviewing our series in the Mississippi State Sanatorium, we have noted definite trends, one of which is parallel, and some a little divergent. The first is that of the aging population. During the past 5 years, the average age of our surgical patients has more than doubled, and it would be even greater than that except for the maximum upper age limit beyond which one cannot be operated upon.

The second has been the factor of increasing bacterial resistance. Over a fourth of our patients operated upon fall into the resistant group. In the patient with open-positive lesions and resistant bacilli, the factors keeping these cavities open and allowing the development of resistance appear to be mechanical—bronchiectasis, bronchostenosis, extreme fibrosis, and enlarged nodes around the hilus of the lung. These have proved to require more extensive resections and although, with the use of ancillary drugs, we feel that the short-term results have been good, we feel that the long-term results are going to be poorer. On the other hand, we have not been able to reduce the extent of our resections very much, and still have to do about 20 per cent pneumonectomies.

(slide) This demonstrates the type of lesion, the totally destroyed lung, for which we are doing pneumonectomies. Nothing less than pneumonectomy will suffice in such cases.

(slide) Thoracoplasties, particularly of the plombage type, remain a very excellent modality of therapy in many patients.

DR. JOHN W. BELL, Seattle, Wash.—I would like to compliment Dr. O'Brien's group on a fine review, and their survival statistics are excellent. However, I believe they are somewhat distressed, as all of us are, with the high incidence of bronchopleural fistulas and space problems after segmental resections. One technique that we developed several years ago was that of reconstitution of the lung. We believe that this technique has contributed greatly to the reduction of bronchopleural fistulas and space problems following segmental resection. Our incidence of 20 per cent dropped immediately to 1 per cent and now, in an experience of more than 200 cases, we have had almost no bronchopleural fistulas and no important space problems. We have had occasional bleeding into the bronchial tree with transient hemoptysis. We have never seen pulmonary infarction as a result of reconstitution.

Several details of the technique are important. The sutures should be placed in a vertical manner parallel to the bronchovascular structures rather than transversely across the vascular tree. It is important to begin the reconstitution at the base of the lung at the level of the segmental bronchus and to re-appose healthy lung tissue over the bronchus. We think this goes a long way in avoiding subsequent fistulas. We do not believe that segmental resections should be used in patients with open-positive disease, and still feel that lobectomy is the preferred operation in the uncontrolled case with resistant organisms.

DR. NORMAN WILSON, Boston, Mass.—I too would like to compliment Dr. O'Brien and his group for their analysis of such a large group of cases and for coming up with so many answers for us I arise merely to pose some questions in view of the trends today in the surgery of tuberculosis Those of you who deal with this subject know that we have reached the stage where we have returned to the era of laudable pus and an open cavity being acceptable in the treatment of tuberculosis, and it is very perplexing to see us return to that era without more evidence than we now have I notice that 18 per cent of their surgical patients had a positive sputum I would like to ask Dr Barrett if this was not a more important factor in all the complications than was age and type of operation, because it has been our experience that the type of operation had absolutely nothing to do with the prognosis of the tuberculous lesion provided you have everything else equal on the board Pneumonectomy with a good contralateral lung and a clean operation in a patient still sensitive to the drugs with long effective chemotherapy following surgery in our experience does as well as does a segmental resection Most pneumonectomy patients do not fall into this category I would like to ask if the extent of disease and bacteriologic status of the patient at the time of surgery were [illegible] more important problems than were the age and other factors Also, I would like to ask whether the exacerbation rate was not also related to the same problems because, in our experience, [illegible] the definitiveness of the operation and the protection postoperatively by effective chemotherapy, not preoperatively, are the factors which keep our patients well

A third question concerns th [illegible] ve sputum [illegible] I believe Dr Barrett will tell us that these patients were p [illegible] sputa [illegible] otherapy In other words, these were not patients who were [illegible] under a [illegible] chemotherapy I would assume they might be those [illegible] failur [illegible] remained positive after many months of therapy, and th [illegible] protection and developed increased resistance to the [illegible]

DR DAY (Closing) W [illegible] ers for their comments Most of them were, I would sa [illegible] ll like to indicate that we are well aware of the pioneer [illegible] hill and Dr Klopstock, and we are greatly indebted to them, of course W [illegible] agreement with the statements of Dr Wilson We had no opportunity, really [illegible] series of this kind, to cover all the points Of course we agree and tried to point out the fact that positive sputum, at the time of or just prior to surgery, was perhaps the most important common denominator of all our difficulties We merely aimed to point out that this factor, together with resistance, advanced age, emphysema, etc, further compromised our results

Dr Bell's comments I am especially glad to hear, because we too try to reconstitute our segmental surfaces as much as possible when they are located in such a fashion that this can be done, we have not seen any of the dire consequences that are alleged to ensue from such a course of action Neither have we seen if I may discuss the last paper at this time too, the phenomenon of infarction to occur as it was said to occur in that series Perhaps it occurred and we did not recognize it If one leaves it alone long enough, the patients usually get well

I think that covers as best I can the various questions asked I might say that our attitude toward resection in general as you can see, has been a conservative one over the years and has not changed appreciably except for the tendency to do fewer pneumonectomies and more segmental and subsegmental resections As Dr Overholt once said when he passed through our place, the errors that are made in resection are usually made as a result of doing less than the lobar unit If there is any question of difficulty to ensue from transecting disease in the intersegmental plane, the lobar unit should be removed Our main indication over the years, of course, has been the open cavity or significant residual following a long period of what we believe to be adequate therapy

It is our feeling that the analysis presented in this report supports the view that resectional therapy is a procedure of proved value and that its continued use is indicated In certain areas, the indications are imperative In the group with small areas of disease, the problem of prophylactic resection is still a controversial subject At the other extreme, in the widely distributed lesions, a compromise with regard to the open-negative lesion sometimes must be accepted, when such factors as age, emphysema, and poor pulmonary reserve combine to increase operative risk significantly.

DR. SALYER (Closing).—I wish to thank the discussers. I should add that this postoperative problem, pulmonary infarction of a subsegment or segment, occurs not only at Fitzsimons, but occasionally at other hospitals where pulmonary resection for tuberculosis is done. Presently, we have two ladies in the hospital who had pulmonary resections elsewhere; they now have pleuropulmonary cavitary lesions at the site of segmental removal and highly resistant organisms. After reviewing serial films, we are certain that they developed this specific complication after resection many months ago.

Secondary thoracotomy has been necessary during the past 2 years in 4 additional patients having similar complications following initial resections elsewhere; varying degrees of drug sensitivity of the acid-fast bacilli harbored in these lesions were demonstrated. Presently, theso patents are doing well.

Perhaps I should not take issue with Dr. Bell's segmental reconstitution technique since I have never used it; however, when listing all the possible etiological factors and mechanisms which may be related to this postoperative complication, we considered the suture approximation of segmental surfaces as possibly contributing to intersegmental venous obstruction and thrombosis.

Two thoracic surgeons formerly assigned to our hospital have employed Dr. Bell's suture approximation technique; initially they seemed to get good results, later they found that hematomas were prone to develop in the approximated intersegmental plane which would separate and result in an air-fluid space. Such patients were subsequently treated by appropriate surgical methods. It is quite possible that they did not perform the procedure as Dr. Bell does it.

SEVEN YEARS' EXPERIENCE WITH TRANSVENTRICULAR AORTIC COMMISSUROTOMY

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THE PROBLEMS associated with the surgical alleviation of aortic stenosis have to date presented far greater difficulties than any of the other stenotic valvular lesions. That this is true has been recognized for many years, since the first surgical attempt to relieve an obstructed aortic valve was made by Tuffier in 1913. The exact nature of these difficulties, however, has been fully appreciated only within the past decade, during the recent renaissance of intracardiac valvular surgery. Although as much, if not more, time and valiant effort (both experimental and clinical) have been directed toward the relief of this most intractable of valvular lesions, as compared to tricuspid, pulmonary, and mitral stenosis, equal success has not as yet been forthcoming. There are a number of reasons for this state of affairs.

PATHOPHYSIOLOGIC CHANGES

1. Anatomically, the valve is the least accessible to exploration, for it lies centrally placed within the confines of the heart. The left ventricular myocardium is invariably hypertrophied to a considerable degree. This finding, together with the tremendous vascular pressure generated within its outflow tract, prevents the use of an immediately subaortic transmyocardial incision for the insertion of the finger or instrument, similar to that used in pulmonary valvotomy, because uncontrollable hemorrhage will surely follow. The valve cannot be effectively reached through an auricular appendage. The position of the ostia of the coronary vessels, lying directly behind the valve leaflets, makes direct reconstructive surgery hazardous. An approach from above, directly through the aortic wall, presents the same difficulties encountered in the immediate subaortic transmyocardial approach and results in a surprising incidence of septicemia. Thus, definitive technical approach to the valve is unfavorable.

2 Pathologically, there is an early fusion of the three valve cusps, the margins of which become thickened, rolled, eburnated, and infiltrated with calcium very early in the course of the disease. This is due in part to the

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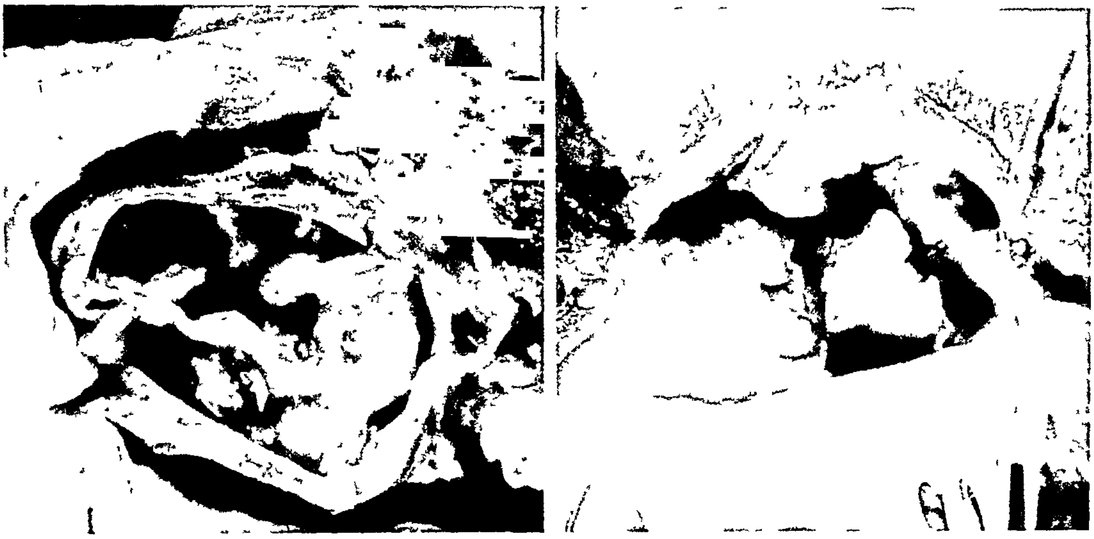
underlying disease itself but also, and perhaps more particularly, to the location of this valve in the course of the bloodstream. The valve lies in a confined space of small diameter and is the recipient of the full head of vascular pressure from the strongest of the contracting cardiac chambers, the left ventricle. The factor of vascular trauma is, therefore, of great importance for, following initial fibrotic agglutination of the cusp margins, there is a constant and steady deposition of traumatic elements, such as fibrin and calcium from which there can be no relief (Fig. 1). Thus, calcification develops early and, as the leaflets are relatively small in surface area, almost complete immobility and fixation may rapidly ensue. Some flexibility of the cusps at their attachment to the aortic ring may remain for a time, but this is less prominent than that seen in the stenotic mitral valve. This factor of trauma no doubt partially explains the fact that the anteromedial leaflet of the mitral valve, also called the aortic or septal leaflet, is the seat of the greatest calcification in mitral stenosis, for it lies nearest the aortic ring in the high flow-pressure area of the left ventricular outflow tract, and also receives the brunt of vascular ejection at the time of left ventricular contraction. Therefore, from a pathologic standpoint, surgical intervention in aortic stenosis, to restore effectively a measure of normal motion of the valve leaflet, must be carried out before extremes of the above-described process are reached. To wait longer merely compounds the likelihood of surgical failure for, following the valvular change, the left ventricular myocardium hypertrophies, dilates, and in due time wears out and becomes incapable of effective action. As the left ventricle is the cornerstone of the heart and circulation, its failure predicates irremediable diaster. This, again, is in contrast to the findings in mitral stenosis, where, despite profound pathologic and clinical changes, even to the point of prolonged congestive failure and invalidism, the left ventricle retains its indispensable function—actual, compensatory, and recuperative—almost to the end.



A. *B.*

Fig. 1.—*A*, The aortic valve viewed from the aorta showing the extremes of induration and calcification resulting in complete fixation. *B*, The same valve from the ventricular aspect.

3. *Physiologically, because of the jetlike ejection of relatively small amounts* of blood with each left ventricular contraction, the systolic blood pressure may not reach high levels although it is perhaps sustained and maintained longer than usual. Diastolic pressures, however, remain high so that the pulse pressure is small and coronary artery filling, now under greater stress because of the demands of an increased myocardial mass, may be inadequate. As such, these patients are often precarious anesthetic risks, to say nothing of the superimposed danger of surgery.

CLINICAL CORRELATION OF PATHOPHYSIOLOGIC CHANGES

To recapitulate, therefore, as a result of these pathophysiologic changes, the ultimate prognosis in a given case of aortic stenosis, almost invariably calcified and immobile, lies purely in the integrity of the left ventricular myocardium. This chamber attempts valiantly to maintain adequate systemic circulation. Myocardial work is required to impart velocity to a necessary volume of blood. As the valve area diminishes, increased propulsive pressures accompanying left ventricular hypertrophy are clinically manifested by forceful heart action and heart consciousness. Added demands for increased cardiac output are thwarted by the unyielding valve, and fatigue and palpitation develop. The left ventricular pressure rises in an attempt to overcome the obstruction; a systolic pressure of 400 mm. Hg represents the extreme in our experience. Once a critical valve area is reached (approximately 0.7 cm.^{2}, according to Gorlin[1]), the heart is unable to maintain an adequate output. Dizziness, syncope, and angina—with or without the specific changes of coronary arterial disease—become evident. The left ventricle under these circumstances must ultimately fail and, *when this occurs, disaster follows in its wake. Pulmonary conges*tion and edema, right heart failure, and the ever-present threat of sudden death are the consequences of this uncompensated phase of aortic stenosis. *Once this stage of diminished cardiac output with failure of the left ventricular* myocardium is reached, the prognosis becomes grave and, as a rule, patients in this predicament have but a matter of months to live.

CLINICAL CLASSIFICATION OF AORTIC STENOSIS

The necessity for translating this inexorable chain of pathophysiologic events into a reasonable, practical, clinical classification, as a basis for surgical intervention is obvious. Such a clinical chain of events through which the average patient with aortic stenosis will pass is readily recognizable, although perhaps not clearly defined in the mind of the physician in the light of surgical advances. For a number of years we have used a system of staging (Table I) so that when the afflicted patient presents himself for evaluation, some estimation of the patient's status in relation to the timing of possible surgical intervention can be made.[2] In this way it is almost immediately possible, within reason, to recognize just where the patient may be in the over-all course of his disease syndrome. Thus, the patient can be more intelligently managed.

TABLE I. CLINICAL CLASSIFICATION OF AORTIC STENOSIS

STAGE	SYMPTOMS
	Before Left Ventricular Failure
I	Asymptomatic—murmur only
II	Fatigue, heart consciousness, palpitations
III	Syncope and/or angina—reduced cardiac output
	After Left Ventricular Failure
IV	Episodic pulmonary congestion
V	Frank congestive failure

Stage I is that period during which the typical systolic murmur of aortic stenosis is present, but before subjective symptoms have resulted. Stage II marks the onset of an ill-defined period in which the patient becomes subjectively aware of his forceful heart action, palpitations develop, easy fatigue becomes noticeable, and his attention may be called to the unusual visible pulsations in his supraclavicular and suprasternal notches. Admittedly, this stage is not specially characteristic of aortic stenosis per se, but when seen in the patient whose cardiac disease is that of aortic stenosis, the combination of the valvular changes and symptoms takes on added significance. It is an indication that the myocardium is beginning to feel the effects of an unyielding obstruction at the aortic level (Fig. 2). Stage III ushers in the obvious period of progressive disability due to a diminishingly effective cardiac output, evidenced cerebrally by spells of dizziness and actual syncope or myocardially by substernal discomfort, tightness, effort-angina indicative of an inadequate coronary flow. With beginning left ventricular failure, Stage IV is characterized by episodes of pulmonary congestion and edema, at first rather easily controlled by medical measures, but shortly to become refractory to even the most vigorous management. Stage V

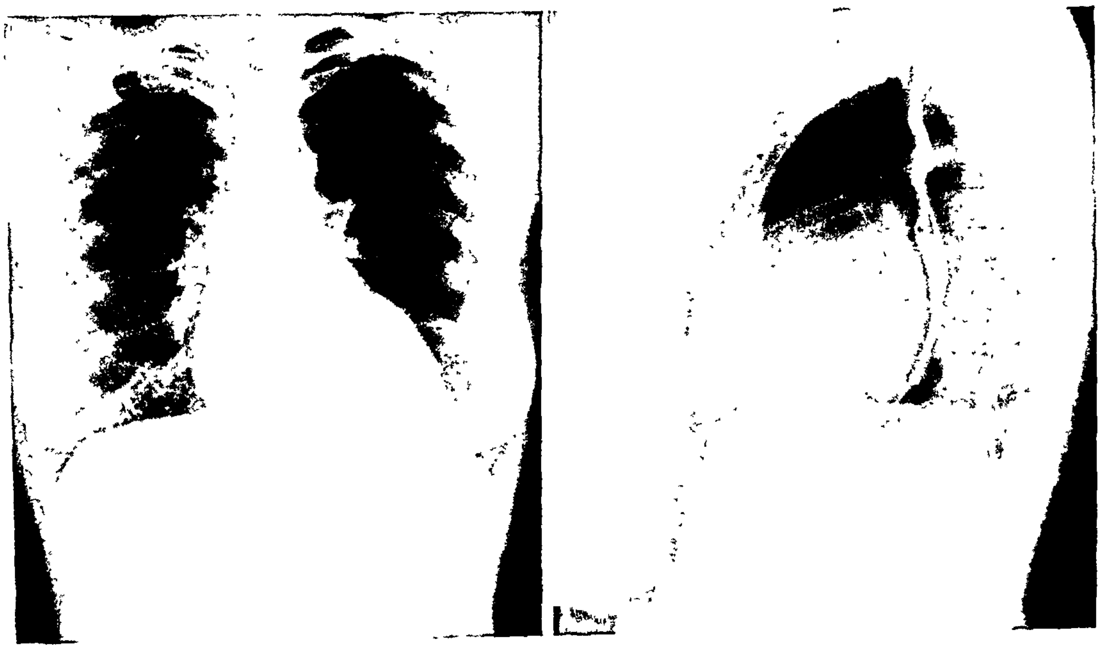


Fig. 2.—Typical cardiac configuration in aortic stenosis before onset of left ventricular failure. Note enlarged left ventricle and ascending aorta.

connotes impending disaster and early demise for, in addition to left ventricular failure, superimposed right heart failure with hepatomegaly, ascites, and peripheral edema now labels the heart picture as one of almost irretrievable damage not to be reversed by any regime, medical or surgical.

With such a progression of easily recognizable clinical findings, it becomes obvious that if surgery is to be of any real benefit it must be performed at a time when the integrity of the left ventricle is still intact. Ideally, therefore, the patient in Stage II would represent the best candidate, for the mortality will be low and the functional result in terms of myocardial efficiency high. Certain it is that the patient should not be allowed to go beyond Stage III for as a rule, even at this relatively late hour, the myocardium has not failed. Once compensation of the left ventricle has been broken, the mortality resulting from surgery, whatever the technique, cannot fail to rise and the ultimate clinical result be reduced. Improved surgical techniques in very recent years have resulted in considerable salvage of patients in Stage IV and even in Stage V, but resort to surgery at this late date is like closing the barn door after the horse has been stolen. These facts will become more obvious with careful study of the clinical data from our own personal experience to be presented below.

HISTORY OF AORTIC VALVE SURGERY

The saga of aortic valve surgery has been a sporadic one. One of the earliest reported approaches to this valve was by Becker, an ophthalmologist (1872)[3] During his study of the retinal vascular changes seen in aortic insufficiency, he lacerated the aortic leaflets in animals, employing a glass rod passed down through the carotid artery into the ascending aorta. Tuffier,[4] in *1913*, is credited with the first direct attack on aortic stenosis in a clinical patient. Although he proposed to incise the stenotic valve in a 36-year-old subject, at the time of surgery he was satisfied to invaginate the aortic wall into the valve orifice manually. The patient survived this procedure. In the light of present knowledge, it is hard to conceive that this method could have effectively relieved much of the stenosis encountered. Brock,[5] in 1947, visualized the aortic valve through the right subclavian artery using a specially designed cardioscope. His intent was to relieve the aortic stenosis by direct instrumentation but, after seeing the irregularly calcified valve which presented itself, it seemed obvious that direct valvotomy could not be carried out without undue risk. A major impetus to aortic valve surgery was provided by Smithy[6] who himself suffered from the ravages of the disease he hoped to be able to control. He concluded from his experimental work that the transventricular route to the aortic valve was preferable. Interestingly enough, he also chose this same approach to the mitral valve.

Experimental studies reported by Bailey, Glover, O'Neill, and Redondo Ramirez,[7] in 1950, included attempts to replace the valve by grafts, bypass procedures to circumvent the aortic valve, backward cutting punches to open the valve commissures, and various modifications of direct valv as suggested by the work of Brock with regard to pulmonary valvotomy. Direct vision replacement of stenotic valves using a baffle clamp was reported by Litwak, Gadboys and their associates in 1952.[8] In 1953, Daniel and Scott[9] attempted to open stenotic aortic valves in 3 patients by direct insertion of a finger through the myocardium of the outflow tract of the left ventricle, but none of these patients survived.

Sarnoff and Case,[10] experimentally, used plastic valves of the Hufnagel type interposed between the left ventricular apex and the aorta to bypass the aortic valve but the high incidence of erythrocyte destruction and resultant emboli precluded clinical trial. Plastic and tissue diverticula sutured to the aortic wall just above the valve area have been used as tunnels to permit digital palpation and manipulation of the valve (Fig. 4). Glenn,[11] Bailey,[12] Swann,[13] and Harken[14] have expressed enthusiasm for this approach. Open cardiac surgical procedures employing hypothermia or extracorporeal bypass have received considerable attention in recent years. Valuable contributions to this aspect of the problem have been made by Swan,[15] Lewis, [16] and Lillehei[17] and their associates. Whereas this latter approach may ultimately be of considerable value in the congenital forms of aortic stenosis when employed at an early age, it would

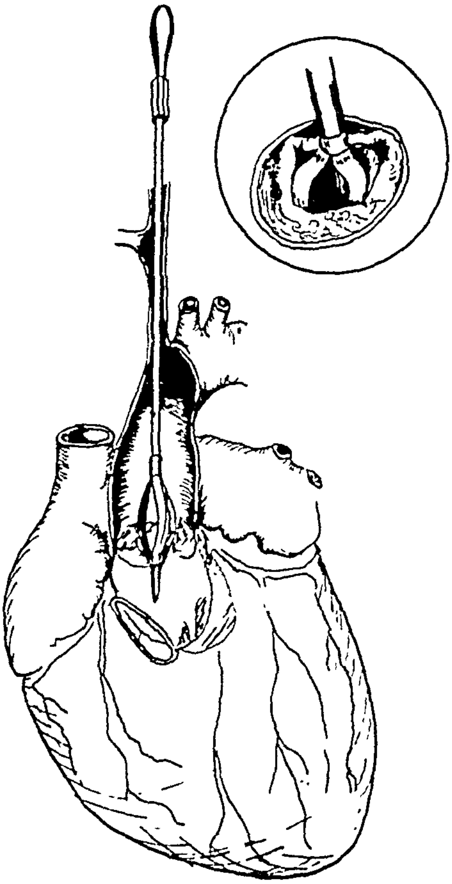


Fig. 3.—An early approach to aortic stenosis using the right carotid artery for the introduction of a valve splitting instrument.

seem to have little place in the surgery of acquired aortic stenosis until such a time as it becomes feasible to resect (totally) the damaged valve and to replace it with a plastic prosthesis.

TRANSVENTRICULAR APPROACH TO AORTIC STENOSIS

Despite the many ingenious approaches outlined, we have been convinced from the inception of modern valvular surgery that until hopelessly diseased and distorted aortic valves can be removed and replaced with impunity, the best functional result with the lowest risk to the patient will be obtained using a properly performed transventricular route. To support this contention, a consecutive series of 78 cases is presented, representing the two phases of transventricular commissurotomy techniques performed in this clinic. This series was begun in March, 1951, and for purposes of this presentation includes every *patient operated upon through June of 1957.* The age range in this group was from 4 to 57 In 24 of these patients, combined mitral and arotic commissurotomies were performed. In one instance, an associated coarctation of the aorta was resected with end-to-end anastomosis, after which the aortic commissurotomy was accomplished. The great majority of these operations were carried out in patients in the far-advanced stages of their disease as seen in Table II. Seventy of the 78 patients had moderate to marked calcification of the aortic valve. Thirteen were in permanent atrial fibrillation (ten of [illegible] were [illegible]fering from both mitral and aortic stenosis).

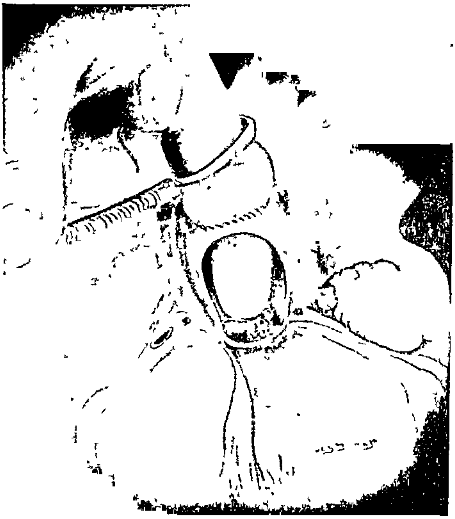


Fig 1.—Approach to the aortic valve through the aorta itself employing a plastic sleeve sutured to the aortic wall for the insertion of exploring finger and instrument.

TABLE II. ANALYSIS OF LATE DEATHS FOLLOWING AORTIC COMMISSUROTOMY

STAGE	NUMBER OF CASES	SURVIVAL PERIOD (MO.)	CAUSE OF DEATH
Old Technique			
II	1	10	Subdural hematoma
III	4	5	Congestive heart failure
		24	Congestive heart failure
		17	Congestive heart failure
		35	Coronary occlusion
IV	1	8	Sudden collapse
V	2		
		41	Congestive heart failure
		5	Pulmonary embolus
New Technique			
III	2	12	Congestive heart failure
		7	Congestive heart failure with aortic insufficiency
IV	3	9	Suicide
		14	Congestive heart failure
		1	Congestive heart failure with aortic insufficiency
V	2	4	Active rheumatic heart disease with bacteremia
		2	Cardiac arrest
	15	1 to 41	

The first 37 cases in this series were operated upon by the old original technique as reported in 1952,[18] employing a large three-bladed expandable split-dilator (Larzelere-Donaldson design) inserted through a widely purse-stringed avascular area near the apex of the left ventricle (Fig. 5). This method has long since been abandoned because of the unwieldiness of the instrument, the unnecessary myocardial trauma, and the excessive blood loss which it occasioned. The remaining 41 patients, operated upon since June of 1955, were operated upon by a greatly refined technique using a dilator demonstrated by Sir Russell Brock.[5] This instrument is light but exceptionally strong, is no larger in caliber than the usual lead pencil, and its expandable head is equipped with two parallel blades rather than three as were formerly used (Fig. 6). It does not cut but dilates the valvular orifice to cause splitting of one or two commissures, occasionally three. Briefly, the technique as employed is as follows: a left posterolateral approach is used entering the pleura through the widely opened fifth interspace giving excellent exposure to the left ventricle and indeed the entire left heart. The pericardium is opened vertically, anterior and parallel to the phrenic nerve from the level of the aortic arch to the diaphragm, thus widely exposing the left heart and great vessels. The aortic ring and its contained valvular tissues are explored externally by palpation and, in most instances, considerable information regarding the type of valve to be encountered, including the degree of calcification and its involvement of the surounding aortic wall or myocardium, can be gained. The ascending aorta is likewise palpated for an estimation of the degree of thrill present and the extent of the poststenotic dilatation of that structure. Direct pressures are taken from within the ascending aorta, the left ventricle and the left atrium. The systolic aortic

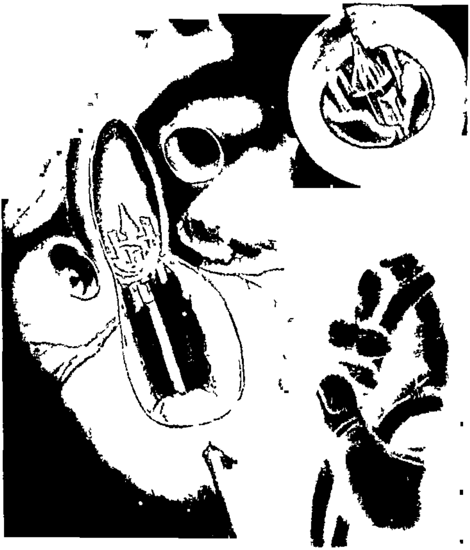


Fig 5 —The original large sized three-bladed aortic valve dilator for transventricular approach to the valve Note guide wire in the aorta over which the instrument is threaded and the wide myocardial purse-string suture employed for hemostasis during manipulation

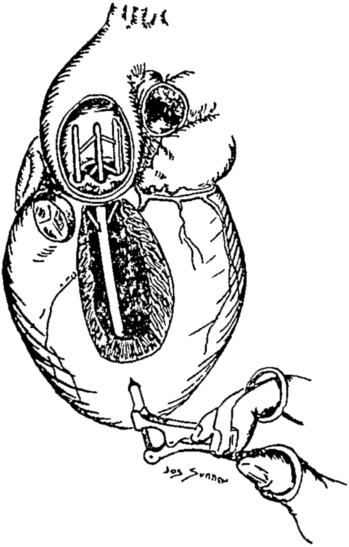


Fig. 6 —The small but powerful two bladed dilator presently for transventricular approach.

gradient indicative of a block has ranged from 30 to 250 mm. Hg in this series. There are those who feel that the measurement of these pressures under aneshesia and in the open chest in this manner is of little value and is not an accurate hemodynamic measurement. While this may be true in the strict academic sense, for practical purposes these measurements are of the greatest value for not only do they give one an estimation of the degree of block, but by comparing pre- and postcommissurotomy pressures very definite knowledge of the efficacy of the procedure performed can be obtained. Indeed most of the pressure tracngs taken in this manner agree amazingly closely to those taken by left heart catheterization prior to surgery, so that we believe that this type of hemodynamic control is absolutely essential to the proper performance of aortic valve surgery. A Statham P23D transducer, using an atmospheric O point, is the type of gauge employed. The head vessels are not isolated or constricted in any manner during the operative procedure. In an experience with over one thouand mitral commissurotomies, no diminution in the incidence of cerebral emboli could be recognized between patients in our series who did not have temporary occlusion of these arteries and in the series of others in which this measure was employed. Indeed, we feel that such a measure is more dangerous than no occlusion at all. Strangely, although one would expect a much higher incidence of emboli in aortic stenosis in which the valves are almost routinely heavily calcified, embolism, in our experience, following aortic commissurotomy has been rare, considerably less than that seen in mitral commissurotomy.

A 1 cm. incision is made halfway through the thickened left ventricular myocardium, so as not to enter the lumen, in an avascular area near the apex of the left ventricle. No bleeding results from this initial incision. No purse-string suture and no stay sutures of any type are used for they tend to damage or crush the myocardium or often pull out with resultant laceration of this muscle. With this technique, bleeding is so minimal that such measures are not needed. It is vital to recognize this fact for this is one of the major refinements responsible for present improved mortality statistics. At this point all is in readiness for the passage of the aortic dilator. The second major feature in this improved technique occurs at this point. All operative manipulation ceases, and for 5 minutes by the clock the anesthetist completely expands the lungs and oxygenates the patient to the fullest. It is felt that this lowers the possibility of myocardial ischemia and resultant arrhythmias during the period of manipulation and, since observance of this feature, arrhythmias other than an occasional premature contraction have rarely been seen. Exposure is then obtained and the two-bladed Brock dilator is gently pressed into the previously initiated incision. As the myocardium contracts and relaxes the dilator held against it with slight pressure dissects its own way through the myocardium into the lumen of the left ventricle. The dilator is then guided upward and passed through the stenotic orifice, being aided in this maneuver by the external hand which is placed about the aortic ring as a target at which to aim. The entire passage of the instrument is done slowly and with deliberation and in a very gentle manner so that there is no jabbing or thrusting under pressure. It is very important to realize that the initial passage toward the aortic valve is downward toward the floor, rather than immediately upward toward the head. This point might be forgotten in the excitement of the operative maneuver. To direct it immediately upward is to impinge upon the interventricular septum or myocardium leading to injury or arrhythmia. A few seconds may be necessary to find the exact orifice for often one impinges upon exuberant calcified plaques and induration occurring in the outflow tract just proximal to the valve or protruding down from the valve itself like thickened stalactites. With care and deliberation there has been no instance where the valve orifice could not easily be entered. The hand (left) which is palpating the aortic ring externally can appreciate the presence of the dilator within the orifice, and can feel half of the dilating head extending out into the aorta itself. When the dilator is properly placed, it is slowly opened to its full extent, first in one plane, and then is carefully rotated in two other planes to ensure the maximum separation of fused valve elements at the commissures. No attempt is made to recognize anatomically each commissure, for these valves are so badly diseased and distorted that such recognition is impossible. The dilator is merely opened where it will, in the three planes mentioned, and routinely the fused valve cone will split at its commissures. One and usually two commissures are readily opened in this manner, occasionally three, although this latter is unusual. One can feel the valve split and crunch as its calcific fusion is split asunder. It is the source of utter amazement that all of these patients do not suffer clinical emboli at this time for, without question, innumerable sandlike particles are dispersed into the circulation but, as stated above, evidence of clinical emboli during the postoperative period rarely is seen. Should the head of the dilator be felt to slip upward into the aorta or backward into the ventricle because of the toughness of the tissues, thereby modifying the splitting compression, the maneuver is repeated rapidly at two or three levels along the outflow tract or up in the aorta to ensure maximum separation of valvular elements. The instrument is closed and slowly withdrawn. Pressure over the small, linear, 1 cm. incision with the finger and a sponge for 1 or 2 minutes will in almost every instance cause complete cessation of bleeding, and with careful manipulation the tiny incision has not been enlarged upward or downward, so that an absolute minimum of myocardium will have been injured. When the heart rate and action is stable and the blood pressure has returned to the same level as it was prior to commissurotomy, the pressures are repeated in the aorta, left ventricle, and left atrium. In most instances, the gradient will have dropped dramatically. In others it will not seem to be entirely effective so that the dilator may be replaced two, three, and even four times, for it is well tolerated as a rule. Occasionally the head of the dilator is removed and another of the same design but larger is attached, a modification of Brock's instrument. This has been effective in further reducing the gradient. In many instances, the gradient has been all but abolished and in many others has dropped to less than 30 mm. Hg. One must remember that often it is obviously impossible to abolish completely the block at the aortic valve level because of the physical presence of large amounts of calcium, the presence of which at this location alone precludes such an accomplishment. Such a valve cannot retract or open completely. When the hopeless nature of the disease present is fully appreciated it will be recognized that the surgeon is attempting merely to improve flow to a maximum degree and not to restore the valve or its action to a normal state, obviously impossible. Most valves in acquired stenosis have lost all semblance of a valve for there is little if any pliability to assure valve action. One is therefore attempting to provide an increased orifice and hopes that some measure of valve motion may be restored, depending upon the individual nature of the particular patient's pathologic changes. Not more than this can be expected until the day when this entire calcified structure can be resected and replaced by a suitable prosthesis.

The tiny myocardial wound is reinforced with two or three heavy sutures, the pericardium is closed completely, a dependent incision having been placed posteriorly for drainage into the pleural space. The chest is closed in the usual manner, using catheter drainage of the pleural space routinely. Recently, in those patients whose myocardium has deteriorated to an exceptional degree or in whom angina pectoris was a prominent preoperative symptom, the internal mammary artery is divided from within the left chest at the level of the second anterior interspace and, after the chest is closed and the patient placed on his back, the right internal mammary artery is divided through a small secondary incision. This feature has been added because of the marked symptomatic improvement obtained in many patients suffering from angina pectoris secondary to coronary insufficiency when this procedure has been employed.[19]

HEMODYNAMIC OBSERVATIONS

In this series of cases, cardiac and arterial catheterizations were carried out preoperatively in 47 instances, this form of study being used only sporadically before June, 1954. When possible, and this was accomplished not infrequently, the arterial catheter placed into the arch of the aorta was passed retrogradely across the aortic valve into the left ventricle. Aortic and brachial artery pressure tracing routinely showed contours suggestive of aortic stenosis with a typical curve, indicating a delayed and notched ejection phase. Cardiac outputs (Fick) varied from 2.10 to 5.96 L. per minute, averaging 3.77 L. per minute for the catheterized series.

As stated, since December, 1954, direct pressure studies have been routinely made at the time of surgery (Fig. 7). The differential pressures before aortic commissurotomy have agreed systematically with the preoperative valvular gradients obtained. The precommissurotomy systolic gradients across the aortic valve have varied from 8 mm. Hg to 250 mm. Hg, averaging 78 mm. Hg. (The patient having only an 8 mm. Hg gradient was operated upon mistakenly, for although her studies and symptoms were characteristic of aortic stenosis, at operation she proved to be suffering from idiopathic hypertrophy of the left ventricle without valvular component.) Postcommissurotomy aortic valve gradients range from 0 to 75 mm. Hg, averaging 27 mm. Hg.

A slightly greater hemodynamic change occurred in the patients who as yet had not gone into failure prior to surgery. Of 19 patients in Stage II or III having operative pressure studies, the left ventricle-aortic systolic gradient averaged 83 mm. Hg before and 29 mm. Hg after commissurotomy, a reduction of 54 mm. Hg, obviously of marked significance. The average systolic gradient in 24 patients in Stages IV and V (after left ventricular failure) dropped from 70 mm. Hg to 28 mm. Hg following commissurotomy (a 42 mm. Hg reduction).

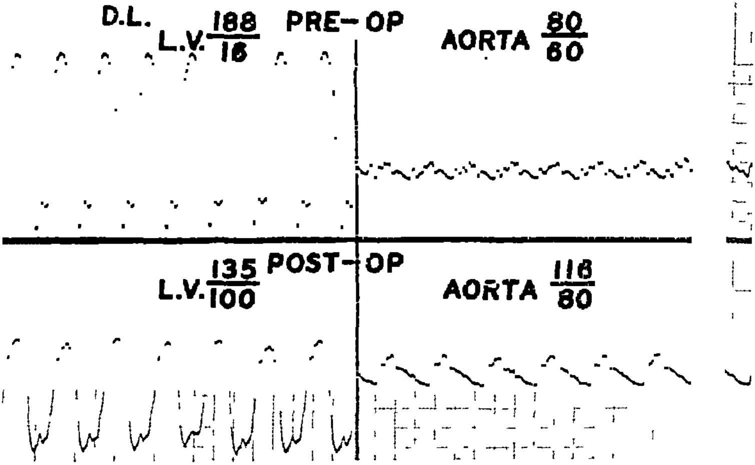


Fig. 7.—Pre- and postaortic commissurotomy pressure tracings taken within the left ventricle and aorta. Note the highly satisfactory reduction of the aortic valve block (from 108 mm. Hg to 19 mm. Hg).

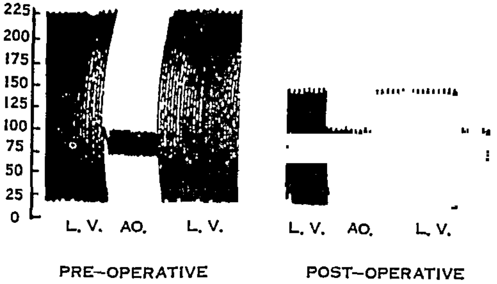


Fig. 8.—Typical hemodynamic response within left ventricle and aorta to transventricular aortic commissurotomy by the method described (recorded at 1 mm./sec. paper speed).

It is obvious that complete abolition of the valvular gradient rarely ensues for reasons considered above, namely, the nature of the pathologic changes present (Fig. 8). These hemodynamic results are an improvement over those which have been published (very few reported) by all other aortic valvular approaches (Fig. 9).

MORTALITY

As yet no appreciable series of patients in whom extracorporeal methods were employed in the relief of acquired aortic stenosis have appeared in the literature, but in a few small series reported the mortality rate has ranged from 50 to 100 per cent. This obviously represents a developmental phase which should be short lived once adequate valvular replacement becomes possible. In the recent past, Bailey has reported an operative mortality of 15.1 per cent using the aortic approach to the valve, but few have attained these results. On the other hand, Brock's success with the transventricular route has been very impressive. His over-all operative mortality has been 16 per cent but in his most recent 63 reported cases, there were but 4 deaths, an extremely respectable 6 per cent mortality.[5]

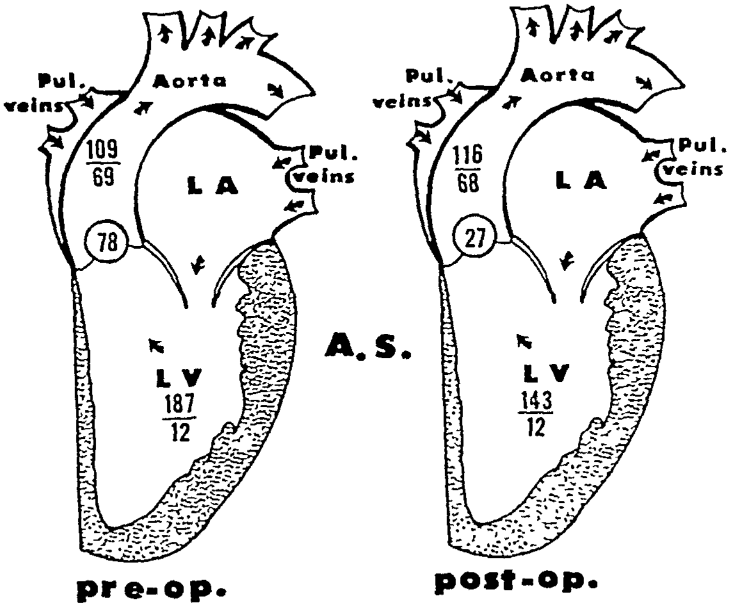


Fig. 9.—Average preoperative and postoperative gradients for the entire series of patients with aortic stenosis.

The deaths in this series of 78 patients are divided into two categories.

Operative Deaths.—Those patients who died in the hospital during or after surgery up to 1 month.

Of the 37 patients operated upon by the older obsolete technique, there were 17 deaths, a mortality rate of 46 per cent, obviously intolerable.

In the more recent group of 41 patients operated upon by the present technique outlined above (since June, 1955), there have been but 2 deaths or a very respectable mortality rate of 4.9 per cent.

In both groups, 17 of the 19 operative fatalities were in patients in the late stages of their disease, having been in repeated cardiac failure (Stage IV or V), and 13 were in Stage V. There were 13 deaths of cardiac origin (mechanism deaths); the remainder occurred during the postoperative hospitalization from congestive heart failure (3), myocardial infarction (1), operative embolus (1), and cerebral vascular accident occurring 10 days postoperatively (1).

Late Deaths.—In the entire series, 15 patients have died since leaving the hospital (1 to 41 months after surgery). Eight of these late deaths occurred in patients who had been subjected to the old operative technique, 7 deaths were in the group who underwent the new operative technique. These data are presented in Table II. It should be added that one of the patients who died at a late date after surgery did not die from his cardiac disease per se for he committed suicide. This was strange for he had obtained a good functional result but lived in fear and dread of his disease potential and could no longer face reality because of this fear.

Although many of these patients have died in various parts of the country, autopsies have been obtained in 16. Coronary occlusion was demonstrated in 2 of these. The coronary arteries were patent in the remaining although some evidence of atherosclerosis was as a rule observed.

CLINICAL RESULTS

The present status of patients presently living has been ascertained by either direct examination or from specific reports from their referring physicians. Twelve of the 37 patients operated upon by the older technique are living to this day (3 to 7 years) and all are distinctly improved. Their ability to work, walk, and indulge in mild exercise is distinctly better than it had been in any time during the years immediately before surgery, so that for them the operation was well worth while. One patient has occasional dyspnea on exertion and another takes infrequent nitroglycerin tablets for chest pain but otherwise remains improved.

Thirty-three of the 41 patients operated upon by the new technique June 1, 1955, to June 1, 1957) have been analyzed, there being a reasonable length of observation of a year or more for analysis. Twenty-five of these are alive and 22 are very definitely improved. These have shown definite symptomatic improvement and in them again surgery has been of great benefit. To be sure, these patients realize that they do not have new hearts or new valves, but are now living with their diseased condition in a vastly improved state but require careful medical observation and management. None of this group has shown signs or symptoms of aortic insufficiency. Nineteen of them have returned to various degrees of work, ranging from housework to welding. The incidence of syncope, dizziness, shortness of breath, chest pain, orthopnea, and recurrent congestive failure has been uniformly improved or in most instances abolished. Thus, 22 of this group of 33 patients in this newer group have been very materially helped by surgery (67 per cent). The remaining 8 patients of the new group of 41 are all living and improved within the first year but not enough time has elapsed to include them in the larger group of late results.

Three patients in the newer group have not been benefited, although they are still alive. One is the patient operated upon with an erroneous diagnosis which proved at operation to be that of idiopathic hypertrophy of the left ventricle without valvular involvement. Another patient, alth hle work intermittently, is orthopneic, has angina, and dizziness, and is unable to climb stairs. The third patient, while improved from the cardiac standpoint, is still recuperating from an operative cerebral embolus (Table III).

TABLE III. LONG-TERM RESULTS FOLLOWING AORTIC COMMISSUROTOMY

STAGE	NUMBER OF CASES	SURVIVAL PERIOD (MO.)	PRESENT STATUS
Old Technique			
II	2	32 and 57	Improved
III	4	38 to 63	2 Improved 2 Excellent
IV	4	37 to 64	Improved
V	2	47 and 65	Improved
Total	12		
New Technique			
II	1	16	Excellent
III	13	8 to 31	5 Excellent 7 Improved 1 Unimproved
IV	9	9 to 22	3 Excellent 5 Improved 1 Unimproved
V	2	10 to 27	Improved
Total	25		

DISCUSSION

It is thought that the technique employing the transventricular route is the best possible form of surgical palliation for aortic stenosis at the present time and until, by open-heart methods, the valve can be replaced. When one considers the pathologic changes with which the surgeon must cope, and realize that the pathophysiologic changes resulting from the disease are inexorable and follow a rather set pattern, it becomes obvious that the only way to improve these results is by earlier selection of patients for surgery. Because, in recent years, most physicians have had considerably more experience with the problems of mitral stenosis than they have had with those of aortic stenosis, much confusion exists as to what constitutes the proper indications for surgery in aortic stenosis. Patients are being referred for operation in aortic stenosis on the basis of indications employed in mitral stenosis. This practice must terminate for the two conditions present major differences. The difference lies in the effects which these two valvular conditions exert upon the integrity of the left ventricular myocardium. The left ventricle is the *cornerstone of the heart.* Despite numerous and repeated bouts of pulmonary edema and right ventricular failure, the left ventricle in mitral stenosis has been spared and remains as a strong and effective chamber. Actually, valvular obstruction at the mitral level has provided a measure of protection. It follows then that decompensation in mitral stenosis is essentially right heart failure and not left. With the establishment of more normal mitral valvular mechanics by surgery, the left ventricle can resume its fundamental role of maintaining total circulation effectively. *Thus, if one waits in mitral stenosis for numerous bouts of congestive* failure to occur, these patients may still be improved to a high degree mainly because of the highly effective action of the left ventricular myocardium. These facts have influenced the physician's thinking and have determined his referral of all valvular patients for operation. The delay in waiting for the signs and symptoms of decompensation to appear is the greatest single factor in the poorer results obtained in the surgery of aortic stenosis.

It must be realized and repeatedly emphasized that from the very beginnings of aortic stenosis the brunt of the obstructive effect is absorbed by the left ventricle itself. It follows, therefore, that when the patient with aortic stenosis shows signs of decompensation, his cardiac failure means left ventricular failure. One cannot wait in aortic stenosis, therefore, until pulmonary congestion or frank congestive failure have developed, for myocardial reserve will then be all but gone. This distinct difference between the effect of mitral stenosis and aortic stenosis must be appreciated to the fullest extent before patients suffering from the latter condition will receive their best possible chance for survival and improvement. One has only to appreciate the fact that 17 of the 19 operative deaths in this series were in patients who had already experienced left ventricular failure to comprehend that new and realistic criteria for operation must be established if these patients are to be given a fighting chance. Furthermore, once surgery has been performed, these patients must not be sent out into the world to fend for themselves, medically speaking. They need careful medical advice and management indefinitely for the future. Even in those patients who have obtained the best hemodynamic response at the time of surgery, one must appreciate the fact that the left ventricle for years has been taxed to its uttermost and now needs intelligent careful support for its remaining lifetime To recapitulate: *when the nature of the pathologic changes in aortic stenosis* is fully appreciated, when the physiologic and myocardial effects of these changes are recognized, when the patient is referred for operation prior to left ventricular failure, and when surgery is performed by a swift and simple technique, then, and only then, will patients suffering from this most difficult of all valvular lesions be given their best chance for survival and maximal functional improvement.

SUMMARY

1. Seventy-eight patients with aortic stenosis have been operated upon by the transventricular approach since March, 1951.

2. The first 37 patients were operated upon using a now outmoded technique, with 46 per cent operative mortality.

3. The last 41 patients have had split-dilatation of the valve by the present method, with 4.9 per cent operative mortality.

4. The average systolic peak gradient across the valve has been reduced from 78 mm. Hg to 27 mm. Hg.

5. There have been 15 late deaths, 8 in the earlier group, and 7 in the group operated upon by the present operative technique.

6. Thirty-four of 37 surviving patients operated on more than 1 year ago have shown definite improvement from their surgery.

7. It is believed that, until the diseased aortic valve can be totally removed and replaced, the transventricular approach offers the best form of surgical palliation with the least possible risk.

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CLOTTING DEVIATIONS IN MAN ASSOCIATED WITH OPEN-HEART SURGERY DURING HYPOTHERMIA

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INTRODUCTION

Open-heart surgery performed under hypothermic anesthesia or with the utilization of an extracorporeal circulation subjects the individual to a stress situation in which the blood is subjected to physical changes in its environment. It is conceivable that the manipulation of tissues, such as the lungs, during the operative procedure may effect the physiologic equilibrium of the clotting and fibrinolytic systems by the release of activators and/or inhibitors into the circulating blood. It is also possible that hypothermia or the use of the pump-oxygenator may induce or enhance changes in the mechanism of clotting. Consequently, we have investigated the nature of the clotting deviations which may occur under these conditions. This communication presents our investigation of the *changes in the clotting mechanism during open-heart surgery under* hypothermic anesthesia. The changes associated with the utilization of the extracorporeal pump-oxygenator are presented in another publication.[10]

PROCEDURE

Citrated plasma (one part sodium citricum tribasicum U.S.P., 3.8 per cent, to four parts of blood) was used throughout the study. The blood was obtained by a two-syringe technique and the plasma was immediately separated by centrifuging the specimen for 5 minutes at full speed in an International clinical centrifuge. The plasma was processed within 30 minutes after the specimen was obtained, and ordinary Pyrex glassware* was used during the determination. The average lowest temperature obtained during hypothermic anesthesia was 28° C. The following clotting tests were performed at both 28° C. and at the conventional test temperature of 37° C.

1. *Recalcification Time.*—This test indicates the over-all coagulability of the blood. In a test tube, 0.03 c.c. of 0.5M $CaCl_2$ was carefully blown into 0.3 c.c. of prewarmed plasma. The end point indicating completion of clotting (recalcification time) is reached when the tube can be tilted to an angle over

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*In most cases.

90 degrees without spilling liquid. Our modification of this test is more sensitive for deviations than the Lee-White time, and undesirable dilutions of plasma are kept at a minimum. This plasma dilution is brought about by the conventional recalcification procedures and disrupts the normal relationship of inhibitors and activators in the plasma. The normal recalcification times at 37° C. are 6 to 10 minutes.

2. *Prothrombin Consumption.*—The prothrombin consumption reflects abnormalities in the first phase of clotting; that is, the thromboplastin formation. This is measured by our own personal method herein described for the first time. The same specimen employed in the recalcification time study is used. Sixty minutes after completion of clotting, the clot was carefully but firmly wound around a small wooden applicator stick and removed from its serum. Then 0.06 c.c. of 3.8 per cent sodium citrate was added to the serum. After an additional 30 minutes (i.e., 90 minutes after the completion of clotting), the prothrombin not consumed during the clotting process was determined in the serum. To 0.1 c.c. of thromboplastin suspension (see below), 0.1 c.c. of fibrinogen solution was added. The fibrinogen solution was made up of 1 per cent bovine fibrinogen Armour dissolved in a mixture of one part of sodium barbital acetate buffer, pH 7.4, and four parts of sodium chloride (0.85 per cent) stirred frequently for 10 minutes with 10 mg. of barium sulfate per cubic centimeter, and the clear supernatant fluid frozen in aliquots. The mixture was prewarmed for 2 minutes at 37° C., at which temperature the final steps of the test were always done, and 0.1 c.c. of the test serum was then blown into it. The clotting time was determined with the sera remaining after clotting at 37° C. and at 28° C. The serum may be stored in the refrigerator for several hours before testing. The normal values for clotting at 37° C. are 40 to 60 seconds.

3. *Prothrombin Activity.*—This conventional one-stage prothrombin time is the result of the combined influence of the activity of prothrombin, factors V and VII (and inhibitors, if present). The gray matter of a fresh human brain, carefully cleaned of meninges and blood traces, is suspended in equal parts by weight of 0.85 per cent sodium chloride by means of a blender, and the mixture frozen in aliquots. An aliquot of this suspension, diluted with ten parts of 0.05M calcium chloride, is used as thromboplastin. The prothrombin activity was read in the usual manner from a plotting graph obtained from the thromboplastin batch which had preserved its full activity for months.

4. *Thrombin Time.*—This test essentially measures the activity of heparin and heparin-like inhibitors. One thousand units of bovine thrombin were dissolved in 5 c.c. of 50 per cent glycerol and stored at −10° C. One part of this solution was diluted in a siliconized test tube with 16 parts of buffered saline (see Prothrombin Consumption) with a pipette, 0.025 c.c. of this resulting solution was blown into 0.2 c.c. of prewarmed (37° C.) citrated plasma and the clotting times were measured. Care was taken to use the thrombin solution immediately after its preparation. Each batch of thrombin was tested on normal plasma. The normal values range from 11 to 13 seconds.

5 *Fibrinolysis*—The following test for fibrinolytic tendency can demonstrate an increased tendency toward fibrinolysis which cannot be discovered in the process of watching "normal" clots One part of citrated plasma was diluted with 18 parts of buffered saline and clotted with 0 01 c c of undiluted thrombin solution The clot dissolution time was measured Undiluted plasma, 0 3 c c, was used and clotted with the same amount of thrombin Normal values are present when there is no fibrinolysis in 24 hours either in diluted or in undiluted plasma upon incubation This method is not accurate when used with heparinized blood In its stead, in studies on heparinized patients, the euglobulin lysis method, which also gives information about the fibrinolytic activity of heparinized blood[11] is to be preferred

6 *Thrombelastography*—This procedure permits continuous recording of fibrin formation and fibrinolysis and gives a good estimate of the firmness of the clot Our technique has been described elsewhere[8]

CLINICAL APPLICATION

There were 11 patients involved in this study Eight of these patients underwent open-heart surgery in association with hypothermic anesthesia while the remaining 3 patients had their procedures performed under normothermia In general, the anesthetic agents used were cyclopropane ether combinations and, in some cases pentobarbital was administered for induction Curare and Prostigmin were given in most instances, and transfusions of stored ACD blood were administered at the beginning of the procedure with the rate of infusion adjusted to the needs of the patient

The patients involved in this study are presented in Table I which includes the age and sex of the patient, the type of operative procedure the duration

TABLE I

NO	PATIENT	AGE	SEX	OPERATIVE PROCEDURE	OCCLUSION (MIN)	LOW TEMPERATURE (DEGREE C)	BLOOD (C C)
1	E C	8	M	Transventricular infundibulectomy, pulmonary valvulotomy	5 20	28 0	400
2	B S	34	M	Division of patent ductus arteriosus	—	27 0	1 500
3	M M	22	F	Suture closure of atrial septal defect	5 20	28 0	1,500
4	R E	14	M	Suture closure of atrial septal defect	7 10	28 0	1,500
5	W S	24	F	Suture closure of atrial septal defect	5 50	26 5	7,800
6	M R	35	F	Suture closure of atrial septal defect	6 15	27 4	2,500
7	C Z	3	M	Pulmonary valvuloplasty	3 00	29 0	300
8	G M	28	M	Suture closure of atrial septal defect	4 20	29 0	2,000
9	R H	6	M	Resection of coarctation of the aorta	—	—	450
10	M F	31	F	Mitral commissurotomy	—	—	800
11	W J	48	M	Thoracoplasty, 3rd stage	—	—	1,700

TABL

PATIENT	RECTAL TEMPERATURE (DEGREES C.)					RECALCIFICATION TIME (MIN.)					SERUM PROTHROMBIN TIME (SEC.)				
	BA*	AA†	AC‡	DO§	CC‖	BA	AA	AC	DO	CC	BA	AA	AC	DO	CC
1	37.2		28.0	28.0	32.0										
37°						5.00		5.30	4.30	5.30	62	—	72	59	116
28°								7.00	4.20	5.45	—	—	62	74	78
2		36.5	32.8	28.0	33.0										
37°							8.30	29.00	19.00	9.30	—	43	35	47	49
28°							7.20	14.00	14.00	9.45	—	47	44	55	60
3	37.0	36.8	30.0	28.9	27.5										
37°						8.00	11.00	8.30	7.00	7.00	42	43	57	58	62
28°						8.30	10.30	7.30	9.45	9.00	54	57	49	55	68
4	37.0	37.5	31.5	28.0	30.0										
37°						5.30	4.00	6.15	4.45	9.00	73	63	62	124	80
28°								5.10	5.30	5.00	—	—	115	114	119
5	37.0	37.0	30.0	27.5	33.0										
37°						8.00	5.00	5.00	5.00	6.00	53	54	53	57	84
28°						6.30	6.30	7.15	7.00	5.30	130	75	79	80	115
6	37.0	37.2	30.0	27.5	32.5										
37°						7.30	8.00	7.30	8.30	6.00	62	65	68	74	79
28°						7.00	8.00	6.30	8.00	7.00	73	76	72	85	94
7			32.2	27.3	36.8										
37°						14.00	19.00	18.30	12.00	10.00	28	33	40	76	75
28°						10.30	13.30	15.00	10.30	8.00	45	64	72	69	99
8	37.2	37.0	32.0	29.5	31.0										
37°						8.00	7.00	4.15	5.30	6.00	57	44	50	65	53
28°						12.00	7.00	4.00	7.00	6.00	109	88	96	88	81
9															
37°						6.00	4.15	—	5.00	6.00	60	69	—	—	140
28°						—	—	—	—	—	—	—	—	—	—
10															
37°						31.00	32.00	—	18.00	16.30	31	32	—	28	35
28°						16.00	17.30	—	12.00	13.30	62	54	—	68	65
11															
37°						14.00	17.00	—	15.00	20.00	44	27	—	40	41
28°						9.00	13.00	—	18.00	12.00	64	60	—	76	80

*BA=Before anesthesia; †AA=After anesthesia; ‡AC=After cooling; §DO=During operation

of inflow-outflow occlusion, the lowest temperature obtained during hypothermia, and the amount of blood infused.

The tests of the clotting mechanism were done at both 37° C. and 28° C. Attempts were made to obtain the blood specimens before anesthesia (BA), after anesthesia but before cooling (AA), after cooling but before operation (BO), during operation immediately after occlusion (DO), and after closure of the chest (CC) in all hypothermic patients (1 through 8); and before anesthesia (BA), after anesthesia (AA), during operation (DO), and after closure of the chest in normothermic patients (9 through 11). In some instances, additional clotting tests were performed on the following day. Our findings for these various determinations are presented in Table II along with the corresponding patient number and the lowest temperature recorded during the period of hypothermia.

PROTHROMBIN ACTIVITY (PER CENT)					THROMBIN TIME (SEC.)					FIBRINOLYSIS (DILUTED PLASMA)					LOWEST TEMPERATURE (DEGREES C.
A	AA	AC	DO	CC	BA	AA	AC	DO	CC	BA	AA	AC	DO	CC	
0	—	53	61	45	—	—	—	—	—	—	—	+++	—	—	28.0
—	—	—	—	—	—	—	—	—	—						
—	50	45	43	40	—	—	—	—	—	—	++	+++	+++	+++	28.0
—	—	—	—	—	—	—	—	—	—	—	—	—	—	+++	
8	44	43	40	37	14.8	16.2	19.5	17.6	18.9	—	—	—	+++	—	28.0
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
0	60	55	40	40	14.7	13.5	16.2	16.5	14.2	—	—	—	+++	—	28.0
—	—	—	—	—	—	—	—	—	—	—	—	—	+++	—	
5	60	60	53	40	14.6	15.5	19.5	17.2	16.5	—	—	—	—	+++	26.5
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
2	51	41	35	33	11.4	14.8	15.2	19.7	14.0	—	—	—	—	—	27.4
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
5	44	43	41	39	12.3	15.0	14.3	14.0	13.4	—	—	—	+++	—	29.0
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
5	55	45	42	43	10.6	12.5	9.8	11.4	12.0	—	—	—	—	—	29.0
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
5	57	—	82	82	12.0	13.0	—	13.3	10.2	—	—	—	—	—	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
45	44	—	43	53	12.0	14.6	—	15.0	11.1	—	—	—	—	++	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
45	55	—	68	63	17.9	18.0	—	17.0	17.7	—	+++	—	—	+++	
—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	

C=After closure of chest.

RESULTS

During the course of open-heart surgery under hypothermic anesthesia, the *recalcification time* exhibited a trend toward shortening rather than toward prolongation. This applied equally to the tests performed not only at 37° C. but also to those at 28° C. In only 1 of 8 patients could a clear-cut but transient prolongation of the recalcification time be observed during the first phase of cooling (patient 2). It is interesting to note that this prolongation was more pronounced in the test done at 37° C. than at 28° C. Consequently, it is doubtful whether the clotting mechanism of this particular patient was even affected since the body temperature was 33° C. at the time of the determination. The lowest temperature reached was 27° C., but the recalcification time gradually returned to normal value. In general, the recalcification times done at 28° C.

TABLE

	RECTAL TEMPERATURE (DEGREES C.)					RECALCIFICATION TIME (MIN.)					SERUM PROTHROMBIN TIME (SEC.)				
ATIENT	BA*	AA†	AC‡	DO§	CC‖	BA	AA	AC	DO	CC	BA	AA	AC	DO	CC
1	37.2		28.0	28.0	32.0										
37°						5.00		5.30	4.30	5.30	62	—	72	59	116
28°								7.00	4.20	5.45	—	—	62	74	78
2		36.5	32.8	28.0	33.0										
37°							8.30	29.00	19.00	9.30	—	43	35	47	49
28°							7.20	14.00	14.00	9.45	—	47	44	55	60
3	37.0	36.8	30.0	28.9	27.5										
37°						8.00	11.00	8.30	7.00	7.00	42	43	57	58	62
28°						8.30	10.30	7.30	9.45	9.00	54	57	49	55	68
4	37.0	37.5	31.5	28.0	30.0										
37°						5.30	4.00	6.15	4.45	9.00	73	63	62	124	80
28°								5.10	5.30	5.00	—	—	115	114	119
5	37.0	37.0	30.0	27.5	33.0										
37°						8.00	5.00	5.00	5.00	6.00	53	54	53	57	84
28°						6.30	6.30	7.15	7.00	5.30	130	75	79	80	115
6	37.0	37.2	30.0	27.5	32.5										
37°						7.30	8.00	7.30	8.30	6.00	62	65	68	74	79
28°						7.00	8.00	6.30	8.00	7.00	73	76	72	85	94
7			32.2	27.3	36.8										
37°						14.00	19.00	18.30	12.00	10.00	28	33	40	76	75
28°						10.30	13.30	15.00	10.30	8.00	45	64	72	69	99
8	37.2	37.0	32.0	29.5	31.0										
37°						8.00	7.00	4.15	5.30	6.00	57	44	50	65	53
28°						12.00	7.00	4.00	7.00	6.00	109	88	96	88	81
9															
37°						6.00	4.15	—	5.00	6.00	60	69	—	—	140
28°						—	—	—	—	—	—	—	—	—	—
10															
37°						31.00	32.00	—	18.00	16.30	31	32	—	28	35
28°						16.00	17.30	—	12.00	13.30	62	54	—	68	65
11															
37°						14.00	17.00	—	15.00	20.00	44	27	—	40	41
28°						9.00	13.00	—	18.00	12.00	64	60	—	76	80

*BA=Before anesthesia; †AA=After anesthesia; ‡AC=After cooling; §DO=During operation;

of inflow-outflow occlusion, the lowest temperature obtained during hypothermia, and the amount of blood infused.

The tests of the clotting mechanism were done at both 37° C. and 28° C. Attempts were made to obtain the blood specimens before anesthesia (BA), after anesthesia but before cooling (AA), after cooling but before operation (BO), during operation immediately after occlusion (DO), and after closure of the chest (CC) in all hypothermic patients (1 through 8); and before anesthesia (BA), after anesthesia (AA), during operation (DO), and after closure of the chest in normothermic patients (9 through 11). In some instances, additional clotting tests were performed on the following day. Our findings for these various determinations are presented in Table II along with the corresponding patient number and the lowest temperature recorded during the period of hypothermia.

PROTHROMBIN ACTIVITY (PER CENT)					THROMBIN TIME (SEC.)					FIBRINOLYSIS (DILUTED PLASMA)					LOWEST TEMPERATURE (DEGREES C.)
A	AA	AC	DO	CC	BA	AA	AC	DO	CC	BA	AA	AC	DO	CC	
0 —	— —	53 —	61 —	45 —	— —	— —	— —	— —	— —	—	—	+++	—	—	28.0
-- —	50 —	45 —	13 —	40 —	— —	— —	— —	— —	— —	— —	++ —	+++ —	+++ —	+++ +++	28.0
8 —	44 —	43 —	40 —	37 —	14.8 —	16.2 —	19.5 —	17.6 —	18.9 —	— —	— —	— —	+++ —	— —	28.0
0 —	60 —	55 —	40 —	40 —	14.7 —	13.5 —	16.2 —	16.5 —	14.2 —	— —	— —	— —	+++ +++	— —	28.0
5 —	60 —	60 —	53 —	40 —	14.6 —	15.5 —	19.5 —	17.2 —	16.5 —	— —	— —	— —	— —	+++ —	26.5
2 —	51 —	41 —	35 —	33 —	11.4 —	14.8 —	15.2 —	19.7 —	14.0 —	— —	— —	— —	— —	— —	27.4
5 —	44 —	43 —	41 —	39 —	12.3 —	15.0 —	14.3 —	14.0 —	13.4 —	— —	— —	— —	+++ —	— —	29.0
5 —	55 —	45 —	42 —	43 —	10.6 —	12.5 —	9.8 —	11.4 —	12.0 —	— —	— —	— —	— —	— —	29.0
5 —	57 —	— —	82 —	82 —	12.0 —	13.0 —	— —	13.3 —	10 2 —	— —	— —	— —	— —	— —	
5 —	44 —	— —	43 —	53 —	12.0 —	14.6 —	— —	15.0 —	11.1 —	— —	— —	— —	— —	++ —	
5 —	55 —	— —	68 —	63 —	17.9 —	18.0 —	— —	17.0 —	17.7 —	— —	+++ —	— —	— —	+++ —	

C=After closure of chest.

RESULTS

During the course of open-heart surgery under hypothermic anesthesia, the *recalcification time* exhibited a trend toward shortening rather than toward prolongation. This applied equally to the tests performed not only at 37° C. but also to those at 28° C. In only 1 of 8 patients could a clear-cut but transient prolongation of the recalcification time be observed during the first phase of cooling (patient 2). It is interesting to note that this prolongation was more pronounced in the test done at 37° C. than at 28° C. Consequently, it is doubtful whether the clotting mechanism of this particular patient was even affected since the body temperature was 33° C. at the time of the determination. The lowest temperature reached was 27° C., but the recalcification time gradually returned to normal value. In general, the recalcification times done at 28° C.

were shorter than the ones of the same plasma specimen done at 37° C. This is well demonstrated in patients 7, 10, and 11 who had long recalcification times at the beginning of the procedure.

The *prothrombin consumption* showed a pattern which corresponds to that of the recalcification time; that is, the prothrombin consumption, reflected by the longer prothrombin serum times, was more complete in the specimens incubated at 28° C. than in those incubated at 37° C. This applied to 40 out of 42 prothrombin consumption tests done at both temperatures. In 2 patients (7 and 10), who had a poor prothrombin consumption at 37° C., the consumption was normalized when the test was performed at 28° C. Generally, cooling failed to bring about any reduction of the prothrombin consumption below the normal values for 37° C. When the blood sample was incubated at 37° C., a decrease in prothrombin consumption in the sample taken after cooling was observed in only 1 patient (patient 2). This was the same patient in whom cooling induced a transient prolongation of the recalcification time for the same specimen. Test tube studies with plasma from normal persons proved that the prolonged serum prothrombin times of samples incubated at 28° C., as compared with those incubated at 37° C., is due to a real and not an apparent increase in thromboplastin formation. It can be said that the prothrombin consumption measured at both temperatures did not show any striking changes in either hypothermic or normothermic patients, except for a trend toward exaggerated prothrombin consumption near the completion of the operation.

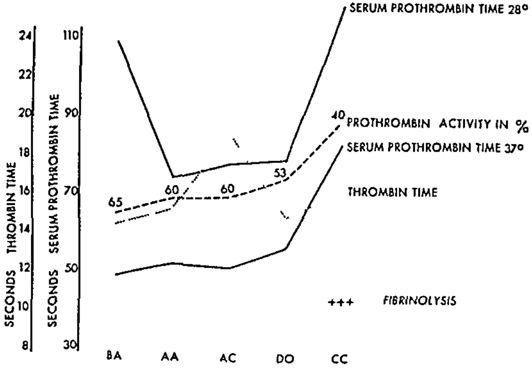
The *prothrombin activity* showed a persistent drop in all 8 of the hypothermic patients during the operation. However, there was a rise in the activity on the day following the procedure. This decrease was not observed in the normothermic group. In fact, in all 3 of these patients, a trend toward an increase of the prothrombin activity was noted during the operation and this was even more pronounced on the day after surgery.

The *thrombin time* frequently exhibited a tendency toward prolongation. In patients, 3, 5 and 6, the thrombin time was shifted during the operation to values which we consider as abnormal. The maximum rise was seen after cooling in patients 3 and 5, and after occlusion in patient 6. Patient 3 had a transient episode of auricular fibrillation during the procedure, but showed no evidence of hemorrhagic manifestation. Patient 6 died the day after the operation after two episodes of ventricular fibrillation. At autopsy, there were large, scattered hemorrhagic areas in the lungs and recent thromboses of both small and large vessels. The rise in thrombin time was accompanied by a very definite bleeding tendency in patient 5. The resulting trends of the clotting tests on this patient are reproduced graphically in Fig. 1.

Coagulograms obtained on this patient clearly indicated that there was a delay in the measurable onset of fibrin formation in the sample obtained after cooling (AC). This same period exhibited the most abnormal thrombin time values. After the thrombin times returned to normal, there was no further evidence of such a delay. Fig. 2 demonstrates this fact clearly.

The tendency toward increased *fibrinolysis* was observed in 8 patients In 3 of the hypothermic group, this fibrinolytic tendency was increased only after occlusion The most persistent lysis tendency was noted in patient 2, in whom many adhesions around the vascular truncus had to be separated In both patients 2 and 4 the increased lysis tendency was also observed in specimens incubated at 28° C In none of the patients could lysis be observed within 24 hours of clots from undiluted plasma obtained on the day of the operation Patient 7 exhibited such a lysis of blood obtained during the first postoperative day

The data of recalcification time and prothrombin consumption given in Table II indicate there is a more complete clotting at 28° C than there is at 37° C In order to establish whether or not this more complete clotting during



clotting mechanism in a 21 year old woman during suture closure
of ler hypothermia Serum prothrombin time (sec) specimen incu
bat thrombin time (sec) at 37° C prothrombin activity (%) at 37°
C of recalcified plasma specimens obtained from blood withdrawn
at dure BA=before anesthesia AA=after anesthesia AC=after
coo on and CC=chest closed

hypothermia is a real one or only an apparent one, a series of two additional test tube experiments were performed Thrombin generation tests were performed by a method of our own, as yet unpublished, using recalcified citrated plasma at 37° C and 28° C, respectively At intervals, aliquots were taken from the plasma, which was in the process of clotting, and added at 37° C to a fibrinogen solution which was clotted by it The clotting speed of the fibrinogen solution is dependent upon the amount of thrombin generated in the clotting plasma, the thrombin amount being related to the amount of thromboplastin formed Fig 3 illustrates the thrombin generation in the clotting mixture which was kept at 28° C proceeds faster and yields more thrombin than in the corresponding mixture incubated at 37° C This becomes particularly evident if a comparison is made of the clotting times of the fibrinogen solution to which an aliquot of plasma in the process of clotting was added after 12 and 16 minutes of incubation, respectively were shorter than the ones of the same plasma specimen done at 37° C. This is well demonstrated in patients 7, 10, and 11 who had long recalcification times at the beginning of the procedure.

The *prothrombin consumption* showed a pattern which corresponds to that of the recalcification time; that is, the prothrombin consumption, reflected by the longer prothrombin serum times, was more complete in the specimens incubated at 28° C. than in those incubated at 37° C. This applied to 40 out of 42 prothrombin consumption tests done at both temperatures. In 2 patients (7 and 10), who had a poor prothrombin consumption at 37° C., the consumption was normalized when the test was performed at 28° C. Generally, cooling failed to bring about any reduction of the prothrombin consumption below the normal values for 37° C. When the blood sample was incubated at 37° C., a decrease in prothrombin consumption in the sample taken after cooling was observed in only 1 patient (patient 2). This was the same patient in whom cooling induced a transient prolongation of the recalcification time for the same specimen. Test tube studies with plasma from normal persons proved that the prolonged serum prothrombin times of samples incubated at 28° C., as compared with those incubated at 37° C., is due to a real and not an apparent increase in thromboplastin formation. It can be said that the prothrombin consumption measured at both temperatures did not show any striking changes in either hypothermic or normothermic patients, except for a trend toward exaggerated prothrombin consumption near the completion of the operation.

The *prothrombin activity* showed a persistent drop in all 8 of the hypothermic patients during the operation. However, there was a rise in the activity on the day following the procedure. This decrease was not observed in the normothermic group. In fact, in all 3 of these patients, a trend toward an increase of the prothrombin activity was noted during the operation and this was even more pronounced on the day after surgery.

The *thrombin time* frequently exhibited a tendency toward prolongation. In patients, 3, 5 and 6, the thrombin time was shifted during the operation to values which we consider as abnormal. The maximum rise was seen after cooling in patients 3 and 5, and after occlusion in patient 6. Patient 3 had a transient episode of auricular fibrillation during the procedure, but showed no evidence of hemorrhagic manifestation. Patient 6 died the day after the operation after two episodes of ventricular fibrillation. At autopsy, there were large, scattered hemorrhagic areas in the lungs and recent thromboses of both small and large vessels. The rise in thrombin time was accompanied by a very definite bleeding tendency in patient 5. The resulting trends of the clotting tests on this patient are reproduced graphically in Fig. 1.

Coagulograms obtained on this patient clearly indicated that there was a delay in the measurable onset of fibrin formation in the sample obtained after cooling (AC). This same period exhibited the most abnormal thrombin time values. After the thrombin times returned to normal, there was no further evidence of such a delay. Fig. 2 demonstrates this fact clearly.

The tendency toward increased *fibrinolysis* was observed in 8 patients In 3 of the hypothermic group this fibrinolytic tendency was increased only after occlusion The most persistent lysis tendency was noted in patient 2, in whom many adhesions around the vascular truncus had to be separated In both patients 2 and 4 the increased lysis tendency was also observed in specimens incubated at 28° C In none of the patients could lysis be observed within 24 hours of clots from undiluted plasma obtained on the day of the operation Patient 7 exhibited such a lysis of blood obtained during the first postoperative day

The data of recalcification time and prothrombin consumption given in Table II indicate there is a more complete clotting at 28° C than there is at 37° C In order to establish whether or not this more complete clotting during

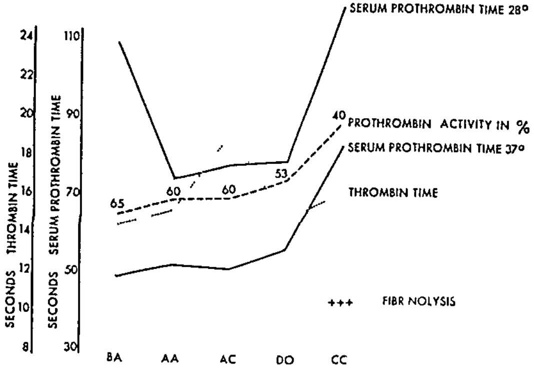


Fig 1—Studies of the clotting mechanism in a 24 year old woman during suture closure of an atrial septal defect under hypothermia Serum prothrombin time (sec) specimen incubated at 37° C and 28° C thrombin time (sec) at 37° C prothrombin activity (%) at 37° C and fibrinolysis tendency of recalcified plasma specimens obtained from blood withdrawn at intervals during the procedure BA=before anesthesia AA=after anesthesia AC=after cooling DO=during operation and CC—chest closed

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It might be concluded that the increased coagulability at the lower temperature is demonstrable only in citrated plasma, which was used throughout the study, and absent in genuine whole blood. To clarify this point, genuine whole blood, obtained from normal individuals with the two-syringe technique, was

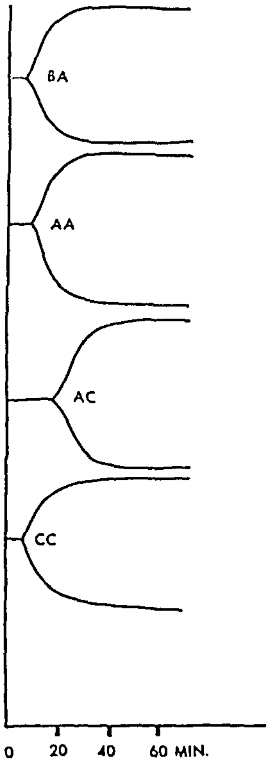

Fig. 2.—Serial coagulograms on Patient No. 5. Fibrin formation begins when the single left side line starts splitting. Note time scale. BA=before anesthesia; AA=after anesthesia; AC=after cooling; and CC=chest closed.

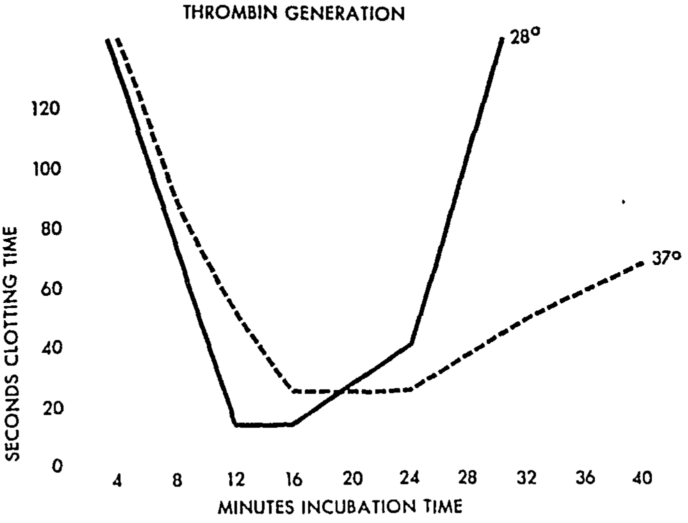

Fig. 3.—Thrombin generation in normal recalcified citrated plasma, incubated at 37° C. and 28° C. Note the formation of more thrombin after a shorter incubation time in the 28° C. specimen.

permitted to clot at 37° C. and at 28° C. in both ordinary and siliconized glass tubes. The clotting time and the prothrombin consumption were measured and reported in Table III. It is evident that whole blood exhibits the same phenomenon as citrated blood. The clotting time at 28° C. is no longer than at 37° C., and the prothrombin consumption is more complete at 28° C. The use of siliconized glassware abolishes this phenomenon. A full account of this and other findings with in vitro clotting studies at various temperatures is now in preparation. A brief preliminary report has been given earlier.[9]

TABLE III

TEMPERATURE (DEGREES C.)	GLASSWARE	CLOTTING TIME (MIN.)	SERUM PROTHROMBIN TIME (SEC.)
37	Ordinary	9	69
37	Silicone	21	22
28	Ordinary	9.3	100
28	Silicone	26	22

DISCUSSION

In a recent paper by Bunker and Goldstein[1] on coagulation in hypothermic patients undergoing major surgical procedures, mainly neuro-surgical in nature, a reduction of prothrombin consumption was reported to occur in some of their patients. It was noted that hypothermia brought about a shortening of the clotting time in some of the patients and the clotting time of the whole blood was not prolonged. The authors discussed the possibility of hypercoagulability or even intravascular clotting at the lower temperature Using our own in vivo and in vitro studies as a basis, we are inclined to suggest that hypothermia combined with extensive surgical procedures could induce hypercoagulability rather than hypocoagulability, provided there does not develop an increase in thrombin inhibitor. The test tube studies indicate that rough surfaces (i.e., non-siliconized glassware) may enhance this phenomenon. These findings are in contrast to the usual opinion expressed in textbooks that the optimum temperature for blood clotting is 37° C. Bugy,[3] after considering his own data as well as those of others, had concluded the optimum temperature for clotting of human blood is 32° C. He feels this is teleologically justified since, under normal conditions, hemostasis is required at skin temperature and not at that of the interior of the body.

Losner and Volk[12] demonstrated that human blood, to which small amounts of citrate have been added, clotted faster at room temperature than at 37° C. They theorized there was a binding of prothrombin and citrate, a union which became firmer with the increase in the temperature. Our test tube studies with unaltered human blood, showing the same increase in prothrombin consumption at 28° C. as that in citrated blood, seem to exclude any important role of citrate. It is possible that at the lower temperatures some naturally occurring inhibitors of the clotting components are less active. This is well known for substances inhibiting thrombin, and many tests, in which the thrombin formed during the procedures is measured, are done with their final steps at 28° C. to reduce the inactivation of thrombin.

The data presented in Table II demonstrate that cooling of human beings during hypothermic anesthesia does not adversely affect their clotting mechanism as measured by the recalcification time and prothrombin consumption. This is in contrast to the results obtained in dogs by some investigators.[7, 17] This animal responds to cooling with a decrease in platelets which we did not observe in man. Although the clotting and fibrinolytic systems of the dog are basically the same as in human beings, there is a different relationship between the individual factors. A comparative study of clot formation by means of thrombelastograms was made by de Nicola[11] in 18 mammalian species. He found the dog's clot formation began normally, but then progressed very slowly to yield eventually a clot with the poorest firmness of all species studied, man included. It is for these reasons that the results of clotting studies in the dog cannot be correlated with those of man without reservation.

As previously mentioned, recalcification time and prothrombin consumption tests do not indicate impaired clotting during hypothermic heart surgery. However, they do indicate the development of a tendency toward increased clotting during the course of the operation. The explanation for this latter phenomenon is not clear. One may postulate that the release of tissue thromboplastin, particularly from the lungs, may play a role. Interestingly, there appear to be two factors working in opposite directions. The first factor, as seen from Table II, is the prothrombin time. This is usually prolonged in the beginning, and has a consistent tendency to become still longer during the operation in the cooled patient. Patients with congenital heart disease are known to have a prolonged prothrombin time. In cases exhibiting atrial septal defects, the range may be from 15 to 70 per cent,[2] while in patients with tetralogy of Fallot or other cardiac defects, the value may be 10 per cent of normal or lower.[6] It is noted that transfusions with stored blood, which has a more or less pronounced deficiency of its prothrombin complex, certainly do not counteract this abnormality. Ellis, Kleinsasser, and Speer[5] believe that intravascular clotting occurs to some degree in all animals undergoing hypothermia and cardiac surgery. They observed a continuous drop in proconvertin, proaccelerin, and prothrombin during the procedure, and assumed that the reduction of the prothrombin complex and the number of platelets can be explained by the consumption of these factors in intravascular clotting. Bleeding may finally develop due to a lack in the various clotting factors. However, we have not seen a bleeding tendency develop due to a frank deficiency in the prothrombin complex. Normally, the moderate deficiency seen in our patients is not sufficient to influence the over-all clotting mechanism.

In this respect, the second factor, the thrombin inhibitor, is more decisive. The thrombin inhibitor is either identical to heparin combined with its co-factor or is related to this complex. It has been described as being elevated in congenital heart disease, the greatest increase in cyanotic patients.[15] The pre-anesthetic values in our patients (2, 3, and 4) are suggestive of such an increase. The thrombin inhibitor can increase rapidly in response to a variety of stimuli. An outstanding experimental example of this is the peptone shock which is combined with a considerable increase in capillary permeability[1] Cooling and rewarming of dogs induced changes of thrombin inhibitor which varied inversely with the temperature[13] It was observed by de Takats[16] that vasodilatation was associated with an increase in heparin secretion In 2 of the 3 patients exhibiting an increase in the thrombin titer, bleeding was encountered or was found at autopsy

It is felt that the increase in thrombin inhibitor and the changes in vascular function associated with it represent the greatest danger in the development of bleeding episodes, and these hemorrhages are not due to the reduction in the concentration of clot promoting factors If sensitive methods are used, the observed increase in fibrinolytic tendency can frequently be found during chest surgery and does not represent a phenomenon due to hypothermic anesthesia However, our results do suggest that circulatory occlusion may favor the development of a fibrinolytic tendency

SUMMARY

The clotting process of human blood as measured by recalcification time and prothrombin consumption is not impaired during hypothermic heart surgery A tendency for hypercoagulability may develop Test tube studies show that clotting is as complete at 28° C as it is at 37° C Patients with congenital heart disease frequently have prolonged prothrombin times which tend to become longer during hypothermia Bleeding episodes may be primarily due to an increase in thrombin inhibitor and the changes in vascular function associated with it

We wish to thank Mrs Edith von Kaulla for her technical assistance in this study

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STUDY OF THE VIABLE INTERCOSTAL PEDICLE GRAFT IN TRACHEOBRONCHIAL SURGERY

Emil Blair, Major, MC, USA, Denver, Colo.

INTRODUCTION

THE availability of material within the chest to repair tracheobronchial defects due either to accident trauma or to elective surgery has been demonstrated by a number of investigators.[1-5] In particular, the work of Penton and Brantigan[3] indicated that a viable intercostal pedicle graft could be used successfully. The advantages of the graft are (1) its viability, and (2) the rigid support provided by bone formation. Logically, it might be anticipated that the presence of a blood supply in a graft should ensure success in healing. Specifically, it should encourage the development of a rich capillary network at the critical line of repair. Furthermore, if the vascularity and nerve supply are maintained, the muscle should retain its integrity and reduce the shortening and/or stenosis secondary to fibrosis and atrophy which would develop as blood flow is reduced or abolished. Finally, epithelization should be encouraged, reducing the magnitude of stenosis. The present study was designed to determine the following: (1) the effectiveness of repair with this type of graft; (2) the contribution of the viability of the intercostal vessels; (3) the histologic changes that may occur during healing; and (4) the subsequent results over a prolonged period of time.

MATERIALS AND METHODS

Mongrel dogs were used, anesthetized with Nembutal, and attached to a positive pressure apparatus for respiration on oxygen. Under sterile conditions, the left chest was entered over the fourth rib. The rib was resected and the graft formed from the fourth and fifth intercostal muscle and neurovascular bundles. The graft consisted of intercostal muscle, artery, nerve and vein, periosteum and pleura.[3] In the dog the pleura is extremely thin and, in the early stages of the study, perforations through the pleura occurred frequently. To eliminate this complication, the pleura was imbricated in subsequent animals. The animals were divided into two groups. Group I consisted of animals in which tracheal defects were created and then repaired with the intercostal pedicle graft. The tracheal window was always sufficiently large so as to preclude adequate closure by primary approximation

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and included at least four tracheal rings. In 4 dogs, a tantalum mesh bridge was placed over the defect before application of the graft. Group II consisted of animals in which the left lung was removed, the bronchus being cut flush with the trachea. The defect then was repaired with the intercostal pedicle graft. The graft was placed in such a manner that the serosal surface faced the lumen of the trachea. The closure was effected with interrupted black silk suture using a single layer. Care was taken in the placement of the graft to avoid kinking of the blood vessels and introduction of the suture either through or around a blood vessel. Despite the precaution, interruption of flow did occur in several instances. However, each pedicle graft had two or more neurovascular bundles so that every graft had at least one intact blood and nerve supply.

Following the closure, the intrapulmonary pressure was elevated by increasing the pressure and flow of oxygen to test for leaks. The chest was then closed in anatomic layers and antibiotics were administered for 1 week postoperatively.

RESULTS

Initially, there were a number of deaths due to perforation resulting from undue tension on the suture line. This was avoided in later animals by making a longer graft and allowing for shortening. The animals were observed for periods of 24 hours to 8 months. A total of 34 dogs were considered satisfactory for evaluation. There were 6 deaths. One was due to atelectasis 9 days postoperatively. The others were due to perforations occurring from 36 hours to 4 days postoperatively. Evaluation was based on recovery from surgery, bronchoscopy at regular intervals, and necropsy with microscopic study.

Group I: *Tracheal Defect and Repair.*—Results are indicated in Table I. There were 20 dogs in this group.

Bronchoscopy: Bulging of the graft into the lumen during the first week was observed except in the dogs which had a tantalum bridge. The surface of the graft showed small circumscribed hemorrhagic areas. In the ensuing 3 weeks, the bulging was reduced. A progressively increasing stenosis was observed in most animals after 1½ months. At this time, the surface assumed the gross appearance of the tracheal lining. In the latter months, the trachea was distorted and pulled to the right, in the direction of the base of the graft.

Necropsy: (Fig. 1.) Within 24 hours, the surface was covered with a smooth fibrin lining 1 to 2 mm. thick which could be elevated easily. The graft protruded into the lumen but caused no serious obstruction. The protrusion declined over a period of 1 month at which time healing was practically complete. There was no bulging in dogs with the tantalum bridge.

Granulomas around the sutures were noted occasionally. Tracheal ring regeneration occurred partially and only in those dogs in which stricture was

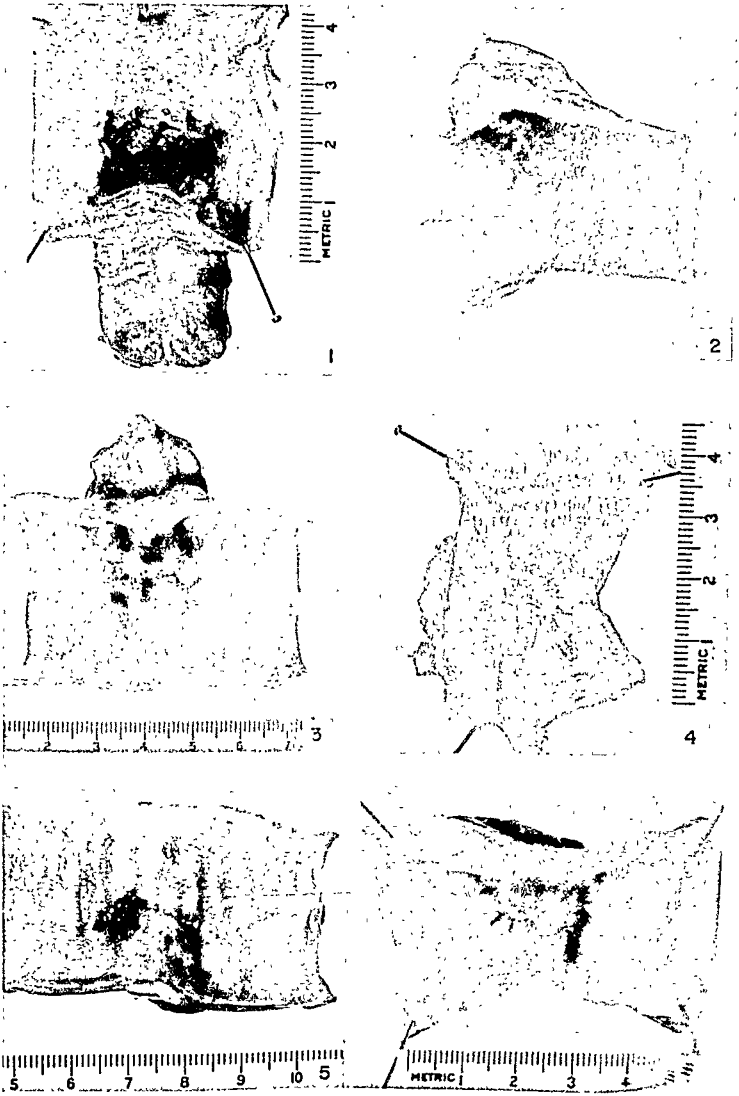

Fig. 1 —Group I. Tracheal [illegible] Hours: Note the [illegible]
(2) Two Weeks: The graft bulg[illegible] lial islands are app[illegible]
Month: Almost complete epitheli[illegible] granulomata. (4) [illegible]
Complete healing with contracture [illegible] nplete healing with [illegible]
(6) Seven Months: Contracture.

TABLE I. TRACHEAL GRAFT (GROUP I)

NO.	DOG NUMBER	PERIOD OF OBSERVATION	CAUSE OF DEATH	DEGREE OF STENOSIS (%)*	EPITHELIAL‡ GROWTH
1	2083	24 hr.	Sacrifice	0	0
2	589T	36 hr.	Perforation	0	0
3	954	36 hr.	Perforation	0	0
4	803T	48 hr.	Perforation	0	0
5	791	9 days	Atelectasis	20†	0
6	433-A	2 weeks	Sacrifice	8	+
7	286-A	1 mo.	Sacrifice	6	++
8	291-A	1 mo.	Sacrifice	2	++
9	331-A	1 mo.	Sacrifice	27†	+
10	422-A	1.5 mo.	Sacrifice	16	++
11	391-A	2 mo.	Sacrifice	6	+++
12	965	2.5 mo.	Sacrifice	0	++
13	962	3 mo.	Sacrifice	25	+++
14	838T	5 mo.	Sacrifice	30	+++
15	818T	6 mo.	Sacrifice	21	+++
16	775	6.5 mo.	Sacrifice	0	+++
17	762	6.5 mo.	Sacrifice	0	+++
18	759	7 mo.	Sacrifice	0	+++
19	783	7 mo.	Sacrifice	25	+++
20	792	7 mo.	Sacrifice	–	+++

T = Tantalum bridge.

$$*\%\ \text{Stenosis} = \frac{\text{Normal trachea circumference} - \text{circumference at stricture}}{\text{normal trachea circumference}}$$

†No stenosis; bulging of tissue into lumen

‡+ = Beginning. ++ = Partial. +++ = Complete.

minimal or absent. In subsequent months, narrowing of the lumen developed in most animals. The degree of stenosis varied greatly. Of 12 animals followed from 2½ to 7 months, 4 demonstrated no stenosis; and 3 others had stenosis to only a small degree. In those with significant stenosis (over 20 per cent), it was never of such a degree as to embarrass respiration as indicated by subjective observation and by absence of emphysematous changes in the lungs on microscopic study. The tantalum bridge did not modify or reduce the degree of stenosis. Epithelial growth was noted to begin at around 2 weeks, until, within 1 to 2 months, the entire operative site was covered with

TABLE II. BRONCHIAL CLOSURE (GROUP II)

NO.	DOG NUMBER	PERIOD OF OBSERVATION	CAUSE OF DEATH	EPITHELIAL GROWTH*
1	2088	24 hr.	Sacrifice	0
2	741	4 days	Perforation	0
3	732	4 days	Perforation	0
4	801	15 days	Sacrifice	+
5	616	1 mo.	Sacrifice	++
6	819	5.5 mo.	Sacrifice	+++
7	654	7 mo.	Sacrifice	+++
8	668	7 mo.	Sacrifice	+++
9	755	7 mo.	Sacrifice	+++
10	777	7 mo.	Sacrifice	+++
11	681	7.5 mo.	Sacrifice	+++
12	726	8 mo.	Sacrifice	+++
13	719	8 mo.	Sacrifice	+++
14	720	8 mo.	Sacrifice	+++

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typical tracheal epithelium. This epithelium assumed the usual morphologic characteristics of tall columnar ciliated cells with a distinct basal cuboidal group (Fig. 2).

Group II: *Pneumonectomy and Bronchial Closure.*—The results are indicated in Table II. There were 14 animals in this group of which 2 died 4 days postoperatively due to perforation around the suture lines. The animals which survived from 15 days to 8 months demonstrated excellent healing and complete coverage of the healed area with tracheal epithelium (Fig. 3).

The Intercostal Pedicle Graft.—

Gross: Within a period of 1 month the graft demonstrated progressive shortening. This shortening resulted in a retraction of the mediastinal contents toward the base of the graft which was lateral and posterior. The graft was firm with considerable bone formation noted frequently. Considerable amount of tissue reaction was demonstrable about the graft investing the trachea and subclavian artery. At no time was the arterial lumen occluded.

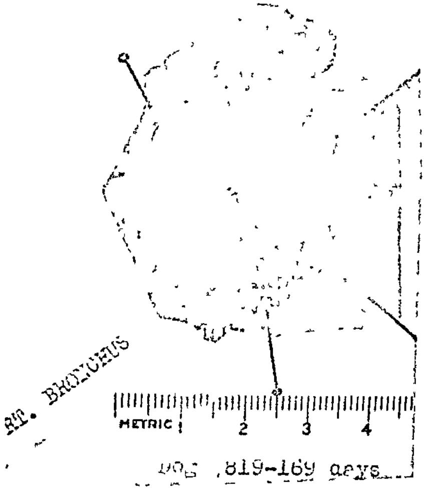

Fig. 2.—Dog from Group II. Open bronchus closed with graft. Well healed with complete epithelial covering.

Microscopic: The essential microscopic changes in the graft are noted in Table III and Figs. 3 and 4. Within 24 hours, an acute inflammatory reaction occurred at the site of anastomosis. Thrombi of small veins, of some arterioles and, occasionally, an artery were observed. However, in every graft, at least one vascular bundle remained patent. The next interval of 9 days demonstrated recession of the acute inflammatory stage and development of chronic inflammatory reaction with foreign body giant cell activity. **At** this time, a

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Group II: *Pneumonectomy and Bronchial Closure.*—The results are indicated in Table II. There were 14 animals in this group of which 2 died 4 days postoperatively due to perforation around the suture lines. The animals which survived from 15 days to 8 months demonstrated excellent healing and complete coverage of the healed area with tracheal epithelium (Fig. 3).

The Intercostal Pedicle Graft.—

Gross: Within a period of 1 month, the graft demonstrated progressive shortening. This shortening resulted in a retraction of the mediastinal contents toward the base of the graft which was lateral and posterior. The graft was firm with considerable bone formation noted frequently. Considerable amount of tissue reaction was demonstrable about the graft investing the trachea and subclavian artery. At no time was the arterial lumen occluded.

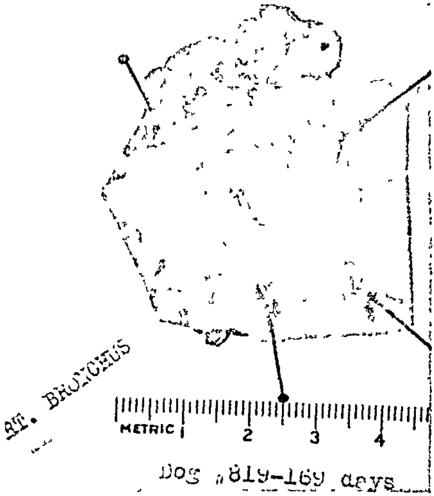

Fig 3.—Dog from Group II Open bronchus closed with graft. Well healed with complete epithelial covering.

Microscopic: The essential microscopic changes in the graft are noted in Table III and Figs. 3 and 4. Within 24 hours, an acute inflammatory reaction occurred at the site of anastomosis. Thrombi of small veins, of some arterioles and, occasionally, an artery were observed. However, in every graft, at least one vascular bundle remained patent. The next interval of 9 days demonstrated recession of the acute inflammatory stage and development of chronic inflammatory reaction with foreign body giant cell activity. At this time, a rich granulating tissue was growing. During the next week, there was a marked increase in vascularity, including development of vessels to the size of arterioles. The intercostal vessels remained patent. At the end of this time (2 weeks), first signs of epithelial growth at the sides adjacent to the trachea were observed.

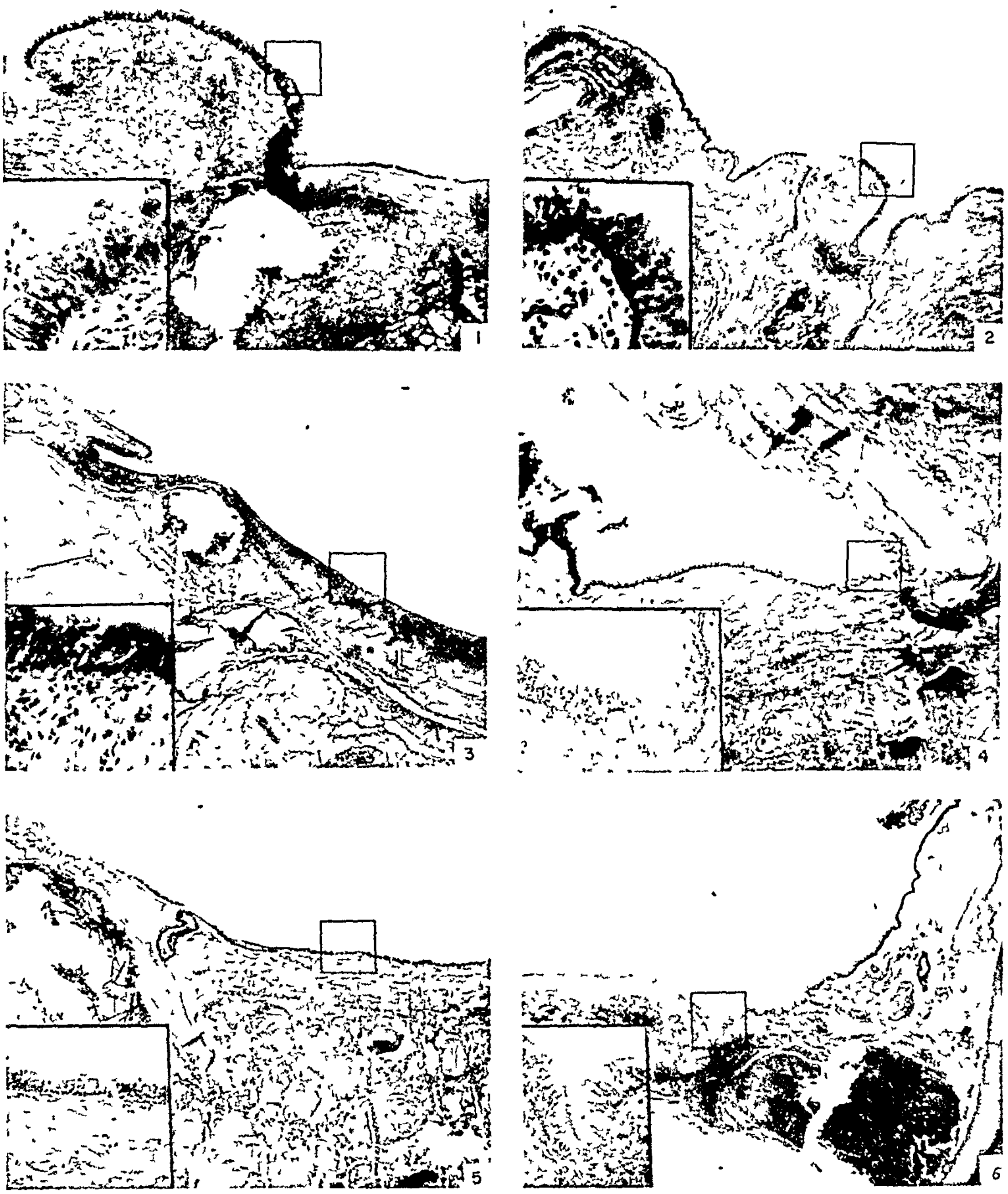

Fig. 3.—Epithelial Growth. Sections are at junction of graft-trachea. Insert is magnified to show epithelial detail. (*1*) Two Weeks: Trachea is at right The newly growing epithelium is typical tracheal lining and rests on a vascular base (*2*) One Month: Trachea is at left Defect was completely covered with epithelium. (*3*) Two Months: Trachea is at right Muscle in graft is undergoing fibrosis and some atrophy. (*4*) Three Months Trachea is at left. No tracheal submucosa developed in any animal. (*5*) Seven Months Trachea is at left Epithelium rests on a fibrous base. Muscle is fibrosed or atrophic Note persistent degenerating artery in right mid-field. (*6*) Eight Months. Trachea is at right Complete atrophy of graft. Chronic inflammatory reaction persists

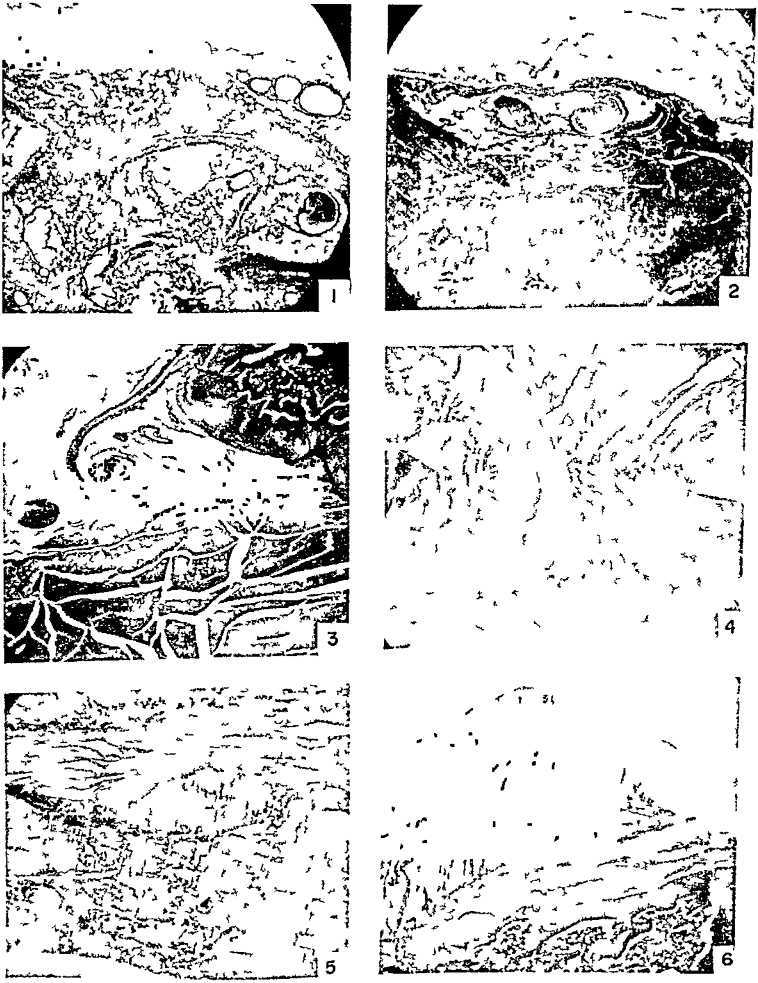

Fig 4—The Intercostal Pedicle Graft (*1*) Two Weeks The intact neurovascular bundle is at the lower right corner Note the extensive vascularity consisting of arterioles and small arteries in addition to capillaries (*2*) One Month The neurovascular bundle is intact The collateral vascularity is reduced Chronic inflammatory elements persist and some atrophic and fibrous changes have occurred in the muscle (*3*) Two Months Note regenerated rib in upper right corner The neurovascular bundle is intact. The muscle in this section retains its normal architecture (*4*) Three Months Regenerated rib and atrophy of muscle is shown (*5*) Seven Months Complete atrophy with replacement of muscle and all vasculature by acellular hyaline material (*6*) Eight Months Note presence of some Graft was almost entirely hyaline and bone

TABLE III. INTERCOSTAL PEDICLE GRAFT

NO.	DOG NUMBER	PERIOD OF OBSERVATION	MUSCLE*	FIBROSIS†	CALCIUM	BONE
1	2083	24 hr.	N	0	0	0
2	2088	24 hr.	N	0	0	0
3	589	36 hr.	N	0	0	0
4	954	36 hr.	N	0	0	0
5	803	48 hr.	N	0	0	0
6	741	4 days	N	0	0	0
7	732	4 days	N	0	0	0
8	791	9 days	N	Min.	0	0
9	433-A	2 wk.	PA	0	0	0
10	801	15 days	N	Min.	0	0
11	616	1 mo.	N	+	0	0
12	286-A	1 mo.	PA	+	+	+
13	291-A	1 mo.	PA	+	+	+
14	331-A	1 mo.	N	Min.	0	0
15	422-A	1.5 mo.	PA	+	0	Yes
16	391-A	2 mo.	PA	+	0	Yes
17	965	2.5 mo.	PA	++	0	0
18	962	3 mo.	PA	++	0	Yes
19	838	5 mo.	PA	++	Yes	0
20	819	5.5 mo.	PA	++	0	0
21	818	6 mo.	A	+++	Yes	Yes
22	775	6.5 mo.	A	+++	Yes	0
23	762	6.5 mo.	A	+++	Yes	0
24	759	7 mo.	A	+++	Yes	Yes
25	783	7 mo.	A	+++	Yes	Yes
26	792	7 mo.	A	+++	Yes	Yes
27	654	7 mo.	A	+++	Yes	0
28	668	7 mo.	A	+++	Yes	0
29	755	7 mo.	A	+++	Yes	0
30	777	7 mo.	A	+++	Yes	0
31	681	7.5 mo.	A	+++	Yes	0
32	726	8 mo.	A	+++	Yes	Yes
33	719	8 mo.	A	+++	Yes	0
34	720	8 mo.	A	+++	Yes	0

*N = Normal. PA = Partial atrophy. A = Atrophy.
†+ = Moderate. ++ = Subtotal. +++ = Total.

In 1 month, epithelization was almost complete. Chronic inflammatory elements persisted while the granulation tissue and capillary activity receded and were being replaced by fibrous tissue. Collaterals, most likely developing from the intercostal arteries, were abundant. The muscle retained its normal architecture.

Significant degenerative changes began to appear between 1 and 2 months. The inflammatory reaction had subsided considerably, but macrophagic activity was still present. The muscle began to show signs of atrophy in the form of hyaline degeneration. The degree of fibrosis increased. The intercostal neurovascular bundle was still intact. In this period, epithelization was complete. Serious muscular atrophic changes occurred in the next 3 and 4 months despite the persistence of patent intercostal vessels. The capillary network had disappeared, and the collaterals were being replaced gradually by fibrous tissue of hyaline materials. The fifth to the sixth postoperative month marked the period of obliteration of the neurovascular bundle, and, except in a few instances, replacement of the muscle by hyaline material and contracted, relatively avascular fibrous tissue In the seventh and eighth months, the graft consisted of masses of hyaline material and contracted fibrous tissue occasionally surrounding bone

DISCUSSION

The intercostal pedicle graft is easily mobilized as sufficient tissue is available for the repair of the defects created in this study The procedure was relatively simple to complete, and the results quite satisfactory With regard to viability, it appears that the blood flow through the intercostal vessels contributed to the early phases of healing and to delaying the atrophic changes in the muscle The presence of a very rich granulation tissue ensured adequate vascularity for healing Further, as opposed to free muscle graft,[9] large caliber collaterals also developed This indicated a greater vascularity than could be achieved with a free graft and likely contributed to the delay in atrophic changes of the muscle Peer has documented that free muscle becomes completely atrophic within 1 month[9] He observed that muscle undergoes atrophy when it is immobilized and not in use This disuse atrophy developed in every dog in the present study, though at a much later period (6 months) At approximately the same time, the neurovascular bundles disappeared

The deposition of calcium and the formation of bone developed as demonstrated elsewhere[3] The fairly early appearance of tracheal epithelium and eventual complete coverage has been consistently observed[3, 6, 8, 10]

Pleura alone or fat has been used with success in the closure of bronchial stumps[1, 2, 4, 5] The results of these studies indicate that a viable graft is not necessarily required to assure adequate closure of a bronchial stump or tracheal defect

The success in healing of tracheobronchial defects as established in this study, was due to the classic mechanisms of healing involving aseptic, careful surgery, the deposition of granulation tissue, and the eventual union by fibrosis The viability, while contributory, does not eliminate the eventual atrophic changes, nor does it accelerate epithelization nor prevent stenosis If there is any question of delay of union or healing because of suspected ischemia or infection, the advantage of a higher degree of vascularity may indicate the use of a viable graft

CONCLUSIONS

1 A viable intercostal pedicle graft consisting of intercostal muscle, the neurovascular bundle, periosteum and pleura was employed to repair tracheobronchial defects

2 The repairs were eminently successful and, although significant degrees of stenosis developed in the trachea, there was no evidence of pulmonary emphysema through the period of 7 months in which these animals were followed

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3. While the viability of the graft may have contributed to the successful healing, union was due to the fundamental classic mechanisms of tissue healing. The viability did not prevent tracheal contracture or atrophy of the graft.

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